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Ready for Takeoff

China's Advancing Aerospace Industry

Roger Cliff, Chad J. R. Ohlandt, David Yang

Sponsored by the U.S.-China Economic and Security Review Commission



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*Cover photo: A Chinese-made ARJ21 commercial aircraft is parked at the 8th China International Aviation and Aerospace Exhibition (Zhuhai Airshow) in Zhuhai, southern coast of Guangdong province, China, November 15, 2010.
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Preface

China's aerospace industry has advanced at an impressive rate over the past decade. While some of this progress can be attributed to rapidly growing governmental support for China's aerospace sector, China's aerospace capabilities have also benefited from the increasing participation of its aerospace industry in the global commercial aerospace market and the supply chains of the world's leading aerospace firms. This monograph assesses China's aerospace capabilities and the extent to which China's participation in commercial aerospace markets and supply chains is contributing to the improvement of those capabilities. Specific areas assessed include China's commercial aviation manufacturing capabilities, its commercial and military capabilities in space, efforts of the Chinese government to encourage foreign participation in the development of the aerospace industry, transfers of foreign aerospace technology to China, the extent to which U.S. and other foreign aerospace firms are dependent on supplies from China, and the implications of all of these issues for U.S. security interests. The study should be of interest to business analysts, policymakers, lawmakers, and anyone who wishes to learn about China's market for commercial aviation, the capabilities of China's aerospace manufacturing industry, the role foreign aerospace firms are playing in the development of China's aerospace capabilities, and security implications for the United States.

This research was sponsored by the U.S-China Economic and Security Review Commission, which was established by Congress in 2000 to monitor and report on the economic and national security

dimensions of U.S. trade and economic ties with the People's Republic of China.

This research was conducted within the International Security and Defense Policy Center of the RAND Corporation's National Security Research Division (NSRD). NSRD conducts research and analysis on defense and national security topics for the U.S. and allied defense, foreign policy, homeland security, and intelligence communities and foundations and other nongovernmental organizations that support defense and national security analysis.

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Summary

China's aerospace industry has advanced at an impressive rate over the past decade. While some of this progress can be attributed to rapidly growing governmental support for China's aerospace sector, China's aerospace capabilities have also benefited from the increasing participation of its aerospace industry in the global commercial aerospace market and the supply chains of the world's leading aerospace firms. This monograph assesses China's aerospace capabilities and the extent to which China's participation in commercial aerospace markets and supply chains is contributing to the improvement of those capabilities. Specific areas assessed include China's commercial aviation manufacturing capabilities, its commercial and military capabilities in space, efforts of the Chinese government to encourage foreign participation in the development of China's aerospace industry, transfers of foreign aerospace technology to China, the extent to which U.S. and other foreign aerospace firms are dependent on supplies from China, and the implications of all of these issues for U.S. security interests.

Chinese airlines, which today operate about 1,400 large commercial aircraft and regional jets, are projected to purchase roughly 4,000 new jetliners over the next 20 years. Actual purchases could be more or less than this projection, depending on whether China's economy grows at the expected rate and on the availability of alternative forms of transportation such as high-speed rail. Chinese air freight companies will likely purchase another 100 to 200 cargo aircraft, but many of them may be converted aging passenger planes. In September 2009, there were about 200 civil helicopters in China, and approximately

1,200 additional civil helicopters are expected to be purchased by 2018. China's general aviation market may be set for an explosion of growth. As of late 2009, the nation's severely restrictive airspace management regime had limited the number of fixed-wing general aviation aircraft in China to about 800 (compared with 230,000 in the United States). Reforms are under way, however, and the number of fixed-wing general aviation aircraft in China is expected to increase by 30 percent per year over the next five to 10 years, resulting in more than 10,000 new aircraft by 2020.

Except possibly in the case of helicopters, China's current ability to meet demand with indigenous aircraft is limited. Its indigenous regional jet, the ARJ21, will begin deliveries in 2011, but the regional jet market in China is small. China's indigenous large commercial aircraft, the C919, will not begin deliveries until the middle of the decade, at the earliest, and it will be a narrow-body aircraft that competes only with the Boeing 737 series and Airbus A320 series. All wide-body aircraft will be imported at least through 2020. Although Chinese airlines will apparently be required to buy at least some C919s, their preference, and that of their customers, will continue to be for Boeing and Airbus aircraft with proven safety and reliability records. If the C919 can establish a comparable safety and reliability record, however, and can offer improved comfort and fuel efficiency, it is possible that, over time, it will begin to take market share away from Boeing and Airbus (provided, of course, that Boeing and Airbus do not bring to market even better aircraft in the meantime).

Chinese manufacturers already produce light utility helicopters and medium transport helicopters, and a medium utility helicopter and possibly a heavy transport helicopter are in development. Given China's limited civil helicopter market, its domestic manufacturing capabilities may be sufficient to satisfy demand, although specialized types of helicopters may be imported. If the fixed-wing general aviation market in China grows as rapidly as projected, much of the demand will be filled by imported aircraft, as the variety of domestic offerings is extremely limited.

The Chinese government has attempted to leverage airliner purchases in exchange for arrangements that it hopes will lead to tech-

nology transfers into China's aviation manufacturing industry. In the ARJ21 regional jet and C919 airliner projects in particular, a condition for foreign aerospace firms to be selected as suppliers has often been that a local production facility be established. Partly as a result of these policies, U.S. and other foreign aerospace manufacturers are engaged in numerous joint ventures and other technology transfers with China's aviation industry. In many cases, however, foreign aerospace manufacturers have established joint ventures in China not to sell products there but to acquire access to China's low-cost, high-quality labor for manufacturing products that are sold throughout the world. As of today, only about 1 percent of U.S. aerospace imports come from China.

China's space capabilities have improved rapidly in the past decade and a half. China's Long March series have arguably become the world's most reliable medium space launch vehicles. China has also developed and deployed a series of weather satellites; electro-optical reconnaissance satellites; position, navigation, and timing (PNT) satellites; ocean-surveillance satellites; synthetic aperture radar (SAR) satellites; high-capacity communications satellites; and possibly signals-intelligence or electronic-intelligence satellites. China has also become the third country to put humans in space. Over the next decade, China's surveillance and reconnaissance, communications, and weather satellite capabilities will undoubtedly improve further, and by 2020, China will likely have a fully deployed satellite PNT system comparable to the U.S. Global Positioning System (GPS).

There is no question that China's growing civilian aerospace capabilities are contributing to the development of its military aerospace capabilities. Many aerospace systems are inherently dual-use or can provide a basis for the development of military systems. Moreover, many of the skills and technologies required to produce commercial or dual-use aerospace products are also applicable to purely military systems. And given that China and the United States have conflicting interests in East Asia and elsewhere, China's growing aerospace capabilities increase its ability and possibly its propensity to use force in ways that negatively affect U.S. interests and would increase the costs—human and material—of resisting such force.

Foreign involvement in China's civil aerospace sector has unquestionably contributed to its development and thus to the development of China's military capabilities. However, it is difficult to quantify the extent to which international cooperation in the civilian aerospace sector is driving improvements in those capabilities. This makes the implications for U.S. security policy unclear. A complete cutoff of international cooperation in the civilian aerospace sector is impractical, as many countries would refuse to go along with such an embargo. A U.S.-only ban would likely slow the development of China's military aerospace capability by only a small amount while handing business opportunities to European and Asian companies and aggravating relations with Beijing. Moreover, conflict or confrontation with China is not inevitable. Thus, whether the United States could significantly improve its security through alterations of its policy toward civil aerospace cooperation with China without having a significant negative effect on its own economic interests is unclear.

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Abbreviations

ABEC	Airbus (Beijing) Engineering Centre
ACAE	AVIC Commercial Aircraft Engines Co.
ACP	Aviation Cooperation Program
APU	auxiliary power unit
AVIC	Aviation Industry Corporation of China
BCF	Boeing Converted Freighter
BSAS	Boeing Shanghai Aviation Service Co., Ltd.
CAAC	Civil Aviation Administration of China
CAFUC	Civil Aviation Flight University of China
CARERI	China Aeronautical Radio Electronics Research Institute
CAS	Chinese Academy of Sciences
CASC	China Aerospace Science and Technology Corporation
CASIC	China Aerospace Science and Industry Corporation
CAST	Chinese Academy of Space Technology
CBERS	China-Brazil Earth Resources Satellite
CCD	charge-coupled device
CETCA	China Electronics Technology Avionics Co., Ltd.
COHC	CITIC Offshore Helicopter Company

COMAC	Commercial Aircraft Corporation of China, Ltd.
CRIAA	China Research Institute of Aero Accessories
CZ	Chang Zheng
DFH	Dongfanghong
DMSP	Defense Meteorology Satellite Program
EASA	European Aviation Safety Agency
ECS	environmental control system
ESA	European Space Agency
EU	European Union
FAA	Federal Aviation Administration
FACC	Fischer Advanced Composite Components
FACRI	Flight Automatic Control Research Institute
FALC	Final Assembly Line China
FSW	Fanhui Shi Weixing
GAP	Goodrich Asia-Pacific Ltd.
GDP	gross domestic product
GE	General Electric
GEO	geostationary orbit
GNI	gross national income
GPS	Global Positioning System
GSO	geosynchronous orbit
HAECO	Hong Kong Aircraft Engineering Co.
HAESL	Hong Kong Aero Engine Services Ltd.
HAIG	Harbin Aircraft Industries Group
HEAI	Harbin Embraer Aircraft Industry
HRC	high-resolution camera

HTAC	Honeywell TAECO Aerospace
HTSL-China	Honeywell Technology Solutions Lab—China
JET	Joint Engineering Team
LAMC	Landing-gear Advanced Manufacturing Co., Ltd.
LEO	low earth orbit
LETRI	Leihua Electronic Technology Research Institute
MBA	Master of Business Administration
MEMS	microelectronic mechanical systems
MEO	medium earth orbit
MOU	memorandum of understanding
MRO	maintenance, repair, and overhaul
NEIAS	Nanjing Engineering Institute of Aircraft Systems
PDL	passenger designated lines
PLA	People's Liberation Army
PNT	position, navigation, and timing
PPP	purchasing power parity
RMB	Renminbi (official Chinese currency)
RPK	revenue passenger-kilometers
R&D	research and development
SAC	Shenyang Aircraft Corporation
SAEC	South Aero Engine Corporation
SAMC	Shanghai Aircraft Manufacturing Co., Ltd.
SAMRI	Shanghai Aero Measurement-Controlling Research Institute
SAR	synthetic aperture radar
SLHC	Sichuan Lantian Helicopter Company

SSAMC	Sichuan Services Aero Engine Maintenance Company, Ltd.
STAero	Singapore Technologies Aerospace, Ltd.
TAECO	Taikoo Aircraft Engineering Co., Ltd.
TCAS	traffic collision avoidance system
WFI	wide field imager
XAC	Xi'an Aircraft Corporation
XAIC	Xi'an Aircraft International Corporation
XRA	XR Aero-components, Ltd.

Introduction

China's aerospace industry has advanced at an impressive rate over the past decade. While some of this progress can be attributed to rapidly growing governmental support for China's aerospace sector, China's aerospace capabilities have also benefited from the increasing participation of its aerospace industry in the global commercial aerospace market and the supply chains of the world's leading aerospace firms. This monograph assesses China's aerospace capabilities and the degree to which China's participation in commercial aerospace markets and supply chains is contributing to the improvement of those capabilities. Most major aviation manufacturers—Boeing, Airbus, General Electric (GE), Rolls-Royce, and Pratt & Whitney—have joint ventures in China or source components from China. China has also received technical assistance from Western companies in the development of airliners, avionics, satellites, and other systems. Although joint ventures and assistance from Western companies are generally confined to purely civilian technologies, this assistance may nonetheless be contributing to the development of China's military aerospace capabilities.

This monograph assesses the growth of China's aerospace capabilities and the extent to which China's participation in commercial aerospace markets and supply chains is contributing to that growth. Specific areas assessed include China's commercial aviation manufacturing capabilities, its commercial and military capabilities in space, efforts of the Chinese government to encourage foreign participation in the development of China's aerospace industry, transfers of foreign aerospace technology to China, the extent to which U.S. and other

foreign aerospace firms are dependent on supplies from China, and the implications of all of these issues for U.S. security interests.

Methodology

The study reported here was fundamentally empirical and inductive. Its primary task was to collect and synthesize publicly available information on China's aerospace capabilities and the involvement of foreign aerospace firms in China. Much of the information used came from Western and Chinese aerospace industry trade publications and from the websites of foreign and Chinese companies.

In assessing the significance of the capabilities and technologies that China is acquiring, the authors drew on their knowledge of the aerospace industry, technology issues, Chinese military capabilities, and U.S. security concerns in East Asia acquired through their academic training, previous work experience, and nearly 20 years of combined experience at RAND.

Structure of the Report

Chapter Two examines China's commercial aircraft market. It assesses the size of the current passenger aircraft market, summarizes projections of its future growth, and analyzes factors that are likely to affect that growth, such as the availability of high-speed rail transport. It also describes the markets for cargo aircraft, helicopters, and fixed-wing general aviation in China.

Chapter Three describes China's current commercial aircraft production capabilities, including those for commercial passenger aircraft, helicopters, and fixed-wing general aviation aircraft. Chapter Four analyzes the role of foreign firms in the development of China's aviation manufacturing industry. It summarizes the policies of the Chinese government toward foreign companies, describes U.S. and other foreign joint ventures and cooperative research and development (R&D)

activities in China, and documents the extent to which China-based production supplies U.S. aerospace firms.

Chapter Five describes China's commercial and military space capabilities. These include launch vehicles, communications satellites, weather satellites, civilian earth-observation satellites, military imagery reconnaissance satellites, and position, navigation, and timing (PNT) satellites. It also assesses the national security implications of China's military space capabilities.

Finally, Chapter Six assesses the rate at which China's aerospace sector has developed, considers aerospace capabilities that China will likely develop in the future, analyzes the potential for China's civilian aerospace capabilities to contribute to the development of military aerospace capabilities, and assesses the implications for U.S. security interests.

China's Commercial Aircraft Market

China is already the world's second-largest national air travel market, trailing only the United States. This market, moreover, is likely to grow rapidly over the next two decades—an estimated 4,000 new passenger aircraft are expected to be purchased by Chinese airlines over this period. This represents approximately one-eighth of the total world demand during the next 20 years. The markets for cargo aircraft, general aviation, and helicopters in China, although significantly smaller than that for passenger aircraft, are also expected to grow rapidly in the coming years.

Current Conditions

In 2007, China's major airlines¹ booked more than 230 billion revenue passenger-kilometers (RPK), or almost 31 billion tonne-kilometers, flown. Passenger-kilometers and tonne-kilometers are standard measures in the aviation industry, where the number of passengers flown or the total weight carried (including passengers) is multiplied by the distance traveled. For comparison, China's RPK is about 20 percent that of U.S. airlines, more than the traffic carried by either German or Japanese

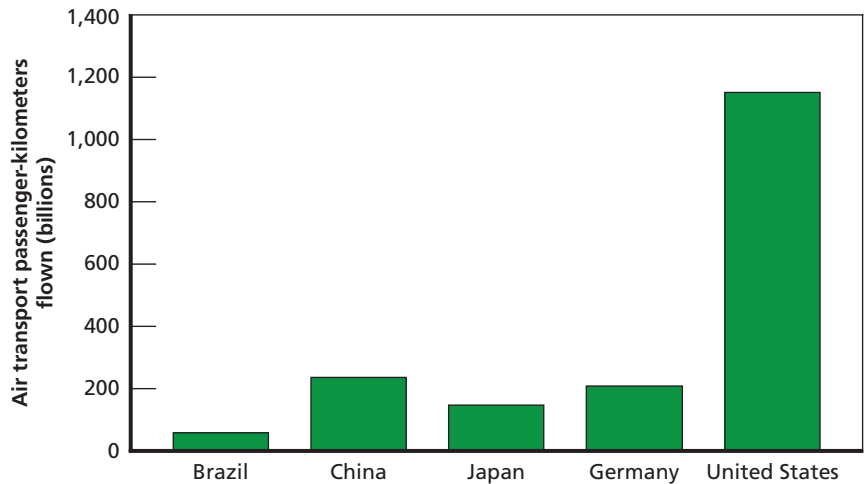
¹ These airlines include Air China, Changan Airlines, China Cargo Airlines, China Eastern, China Southern, China Xinhua, and Hainan Airlines. The three government-created majors—Air China, China Eastern, and China Southern—account for about 85 percent of the Chinese airline traffic. Hainan Airlines accounts for roughly another 10 percent.

airlines and about 6.7 percent of all world traffic in 2007 (International Air Transport Association, 2008). See Figure 2.1.

To support that level of air transport, Chinese airlines used a fleet of roughly 1,350 large commercial aircraft and 60 regional jets in 2010 (World Aerospace Database). The large commercial aircraft fleet comprises 55 percent Boeing airplanes and 43 percent Airbus airplanes. Most of the remaining 2 percent are McDonnell Douglas aircraft produced before McDonnell Douglas's merger with Boeing. The Chinese commercial fleet is approximately 20 percent the size of the North American-based large commercial aircraft fleet and just over 7 percent of the world fleet.

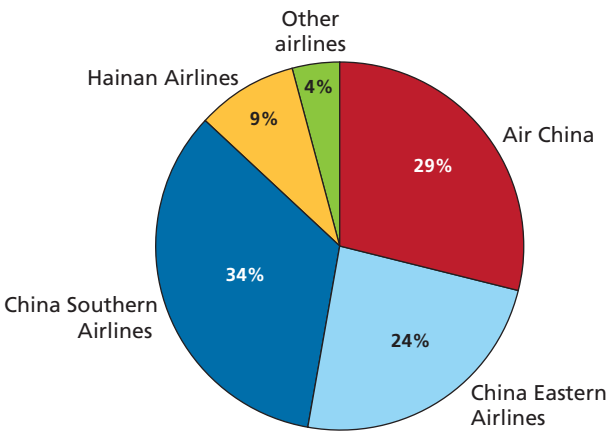
China's commercial aviation market is dominated by the "big three"—Air China, China Eastern, and China Southern. These airlines were created by the Civil Aviation Administration of China (CAAC) in 2000 and 2001 to rationalize the air transport market (Chung, 2003). They are all effectively controlled by the central government. Hainan Airlines is the largest private startup airline. Figure 2.2 shows the RPK distribution of all Chinese airlines.

Figure 2.1
RPK Flown by Major Airlines of Brazil, China, Japan, Germany, and the United States in 2007



SOURCE: International Air Transport Association, 2008.

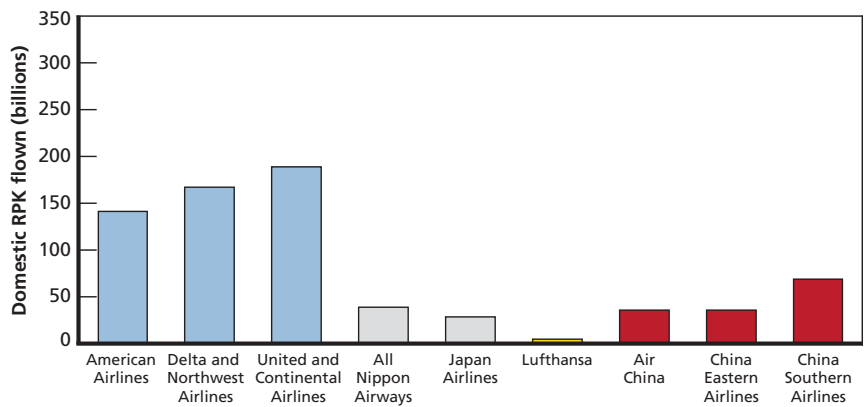
Figure 2.2
RPK Distribution of Chinese Airlines



SOURCE: International Air Transport Association, 2008.
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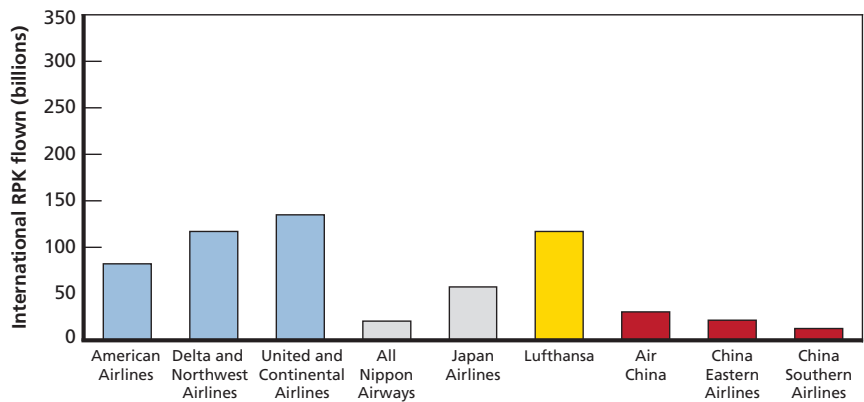
Figures 2.3, 2.4, and 2.5 compare international, domestic, and total RPK of major airlines in the United States, Japan, and Germany with that of the three largest Chinese airlines. In 2007, China’s “big three” were in the top 10 airlines worldwide in domestic RPK, but

Figure 2.3
Domestic RPK Flown by Major U.S., Japanese, German, and Chinese Airlines



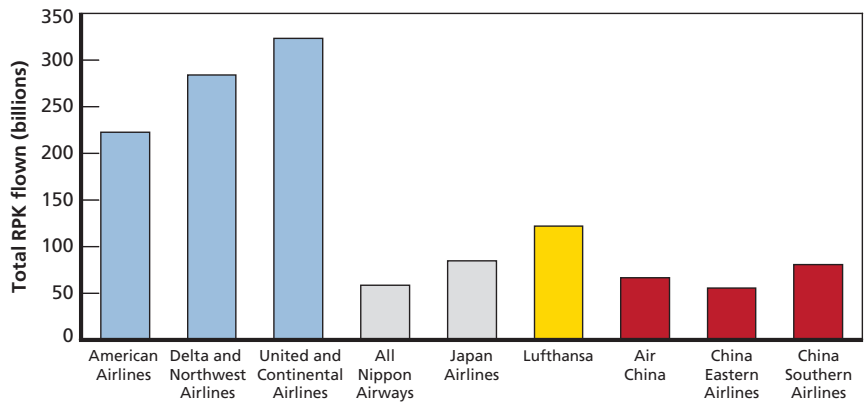
SOURCE: International Air Transport Association, 2008.

Figure 2.4
International RPK Flown by Major U.S., Japanese, German, and Chinese Airlines



SOURCE: International Air Transport Association, 2008.

Figure 2.5
Total RPK Flown by Major U.S., Japanese, German, and Chinese Airlines



SOURCE: International Air Transport Association, 2008.

not in the top 20 for international RPK. In total RPK, they held the 13th, 18th, and 21st positions (International Air Transport Association, 2008). This suggests that they are major world airlines, but their

size is heavily dependent on the domestic market, which is protected from foreign competition, as most domestic air markets are. In the international market, their relatively smaller share of traffic suggests that they are not yet competitive with other international air carriers.

The dedicated air freight market, like the passenger market, has above-average growth rates in Asia. However, air cargo accounted for less than 6 percent of departures worldwide and less than 8 percent of kilometers flown in 2007, according to the International Air Transport Association (2008). Boeing projects a demand for 2,490 freighters worldwide over the next 20 years (Boeing, 2010, p. 10), but more than two-thirds of those will be converted from aging passenger planes. Similarly, Airbus estimates a demand for 3,439 freighters but expects that 75 percent of the demand will be met with converted passenger planes, leaving only 800 to 1,000 purpose-built freight aircraft. Airbus projects the Asia-Pacific freighter fleet to account for 37 percent of the global freighter fleet by 2028 (Airbus, 2009, p. 153). If 37 percent of 1,000 air freighters built over the next 20 years are sold in Asia, this will not significantly affect the total number of large commercial aircraft expected to be sold in China during that period. The total will probably be around 4,000 (see below), even if all 370 newly built freight aircraft are purchased by China.

The development of the rail and highway systems within China is likely to have minimal impact on future air freight trends. Air freight is the most expensive method for moving cargo, and it is generally only used when transit time is an issue or the cargo has a high-monetary-value density, e.g., fresh flowers or computer chips. Improvements in China's rail and highway system are unlikely to result in a significant proportion of the relatively small amount of domestic freight that currently travels by air being shifted to ground transportation. In any case, most of China's air freight traffic is international, and improvements in China's domestic road and rail system are unlikely to reduce travel times by a significant enough amount for cargos that can be delivered by air in a day or two to instead be sent by ship, rail, or truck.

China's general aviation sector is still in a relatively early stage of development. According to CAAC sources, as of the end of 2009, there were only 997 registered fixed- and rotary-wing general aviation

aircraft, including law-enforcement helicopters, in the country. In contrast, at least 230,000 general aviation aircraft were registered in the United States (Cheng, 2010). At present, China simply has not developed an adequate physical or regulatory infrastructure for general aviation. As of the end of 2008, it had only 71 airports for general aviation, apart from the 160 airports used for scheduled flights (compared with more than 18,000 general aviation airports in the United States), and the country also had a serious shortage of general aviation pilots (Li and Wang, 2009, p. 52). In particular, China's severely restrictive airspace management regime is widely considered to be a bottleneck to the development of the general aviation market. Low-altitude airspace is restricted in most of China, and most general aviation flights must secure prior clearance, a process that typically takes at least several days (Xin, 2006). However, as of October 2010, reforms were under way to lift the restriction on low-altitude airspace (below 1,000 meters), starting with Guangdong and the three Manchurian provinces on a trial basis (Wang and Xin, 2010).

Although airspace management reforms have been slower and more limited than many Chinese analysts had wished (Wang and Xin, 2010), the analysts are hopeful that the reforms will help propel the "takeoff" of Chinese general aviation. According to CAAC projections, by the end of the 12th Five Year Plan (2015), China is expected to require between 10,000 and 12,000 general aviation aircraft of various types. During the next five to 10 years, the number is expected to increase by an average of 30 percent annually, and the value of the general aviation market is expected to reach more than 1 trillion Renminbi (RMB) (Meng, 2010). It should be noted, however, that such projections are often based on perceived potential market demand alone. They do not account for serious supply-side bottlenecks such as the shortage of general aviation airports and qualified pilots.

A particularly attractive segment of the general aviation market may be business aviation. According to industry data, as of the end of 2009, there were 50,000 business aircraft in the world, 18,000 of them in the United States alone. Even a developing country such as Brazil

boasted 2,000 business aircraft, whereas China had only 30 in commercial operation at that time. At present, China has an import tariff of 4 percent and a value-added tax of 17 percent on business aircraft, but these have done little to dampen the rapid expansion in business aviation in recent years: Deer Jet (a subsidiary of Hainan Airlines), by far the largest charter aircraft company in China, with 84 percent of the charter market, has seen its operational volume increase by 21 percent in 2008 and 32 percent in 2009, with a projected 60-percent increase in 2010 (Shi, 2010, p. 69). According to 2009 projections by Bombardier, between 2009 and 2018 the Chinese market will require at least 300 business aircraft, while more-optimistic projections put the figure at as high as 1,000 or more (Shi, 2010, pp. 67–68). Since China does not appear to have an indigenous business-aircraft development program, all of these aircraft will presumably have to be imported.

As of September 2009, China had a total of 208 civil helicopters (including those in police and emergency service), more than half of which were light helicopters weighing 4 tons or less (Zhao and Ma, 2009, p. 64). There were only 12 civilian maritime search and rescue helicopters in the country and, as of July 2008, fewer than 30 police helicopters spread across 13 police departments (“China’s Police Helicopter Starts,” 2008, p. 45). As of 2009, there were roughly 0.16 civil helicopters per million residents, compared with 59.41 for Australia, 41.33 for the United States, 4.28 for Brazil, and a global average of 4.8 (Zhao and Ma, 2009, p. 64; Zhang, 2008, p. 37).² Most of China’s civil helicopters are imported—in 2007, only five of the 138 helicopters registered to civil general aviation companies were domestically produced (Zhang, 2008, p. 37).

Assuming an average annual gross domestic product (GDP) growth rate of 8 percent, Chinese aviation officials project that the Chinese civil market will have a total requirement of 1,440 helicopters by 2018, requiring approximately 1,250 new deliveries. If these projections are correct, the Chinese market will account for nearly 10 percent of the 12,700 civil helicopters projected for delivery worldwide between 2010 and 2017 (Xia, 2009, p. 58).

² The figures for Australia, the United States, Brazil, and the global average are for 2006.

Projections of China's Future Commercial Passenger Aircraft Market

Air transit growth is generally characterized by continuous steady growth punctuated by an occasional major setback, such as occurred in 2002 following the 9/11 terrorist attacks or in 2009 following the world financial meltdown. Historically, a country's air transport volume has grown faster than its GDP. This results from increases in GDP per capita, which correlate with growth in disposable income and the time cost of business travelers relative to air travel costs.

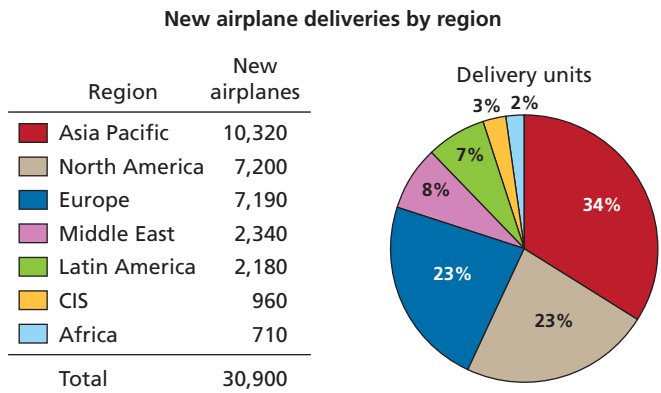
Boeing's *Current Market Outlook 2010–2029* predicts world GDP growth at 3.2 percent and RPK growth at 5.3 percent over the next 20 years. This implies 3.3 percent growth in the world airliner fleet over the same time period (the number of airliners does not increase as fast as RPK because the average size of airplane used is also projected to increase). According to Boeing's calculations, that translates into a demand for 30,900 new airplanes over the next 20 years, with more than one-third of those in the Asia-Pacific region, nearly doubling the size of the world's airplane fleet, from 18,890 in 2010 to 36,300 in 2029 (Boeing, 2010). See Figure 2.6.

Boeing defines the Asia-Pacific region as China, India, Japan, Australia, and all of Southeast Asia. The anticipated demand of 10,320 airplanes includes regional jets, but they will account for only 5 percent of the total, according to Boeing.³ Boeing predicts that Asia-Pacific passenger traffic will grow from approximately 0.8 trillion RPK to 3.4 trillion RPK, with more than one-third of that growth coming from Chinese domestic traffic.⁴ Boeing appears to anticipate that Chinese airlines will purchase 38 percent of the 10,320 aircraft, or about 3,900 new aircraft, over the next 20 years for their domestic market. Boeing thus expects Chinese airline demand for airplanes to be at least 12 percent

³ Embraer, on the other hand, estimates that Chinese airlines alone will take delivery of 950 regional aircraft over the next 20 years (Francis, 2010c).

⁴ Boeing predicts that Asia-Pacific passenger traffic will grow from 0.6 trillion RPK to 2.1 trillion RPK, not counting Chinese domestic traffic, implying that domestic Chinese traffic will grow from 0.2 trillion RPK to 1.3 trillion RPK (Boeing, 2010, p. 5).

Figure 2.6
Boeing's Market Outlook for 2010–2029



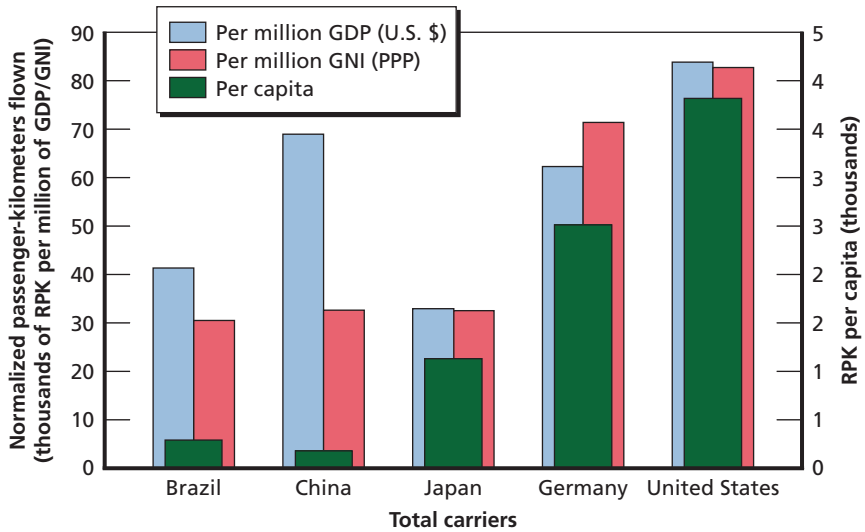
SOURCE: Boeing, 2010. Used with permission.
RAND MG1100-2.6

of world demand and perhaps more, given their share of international traffic (Boeing, 2010).

Because Boeing hopes to sell airplanes and thus is likely to be optimistic in its projections, it is prudent to calculate an independent estimate of the size of China's future aircraft market. Figure 2.7 shows RPK flown in Brazil, China, Japan, Germany, and the United States as a proportion of GDP in U.S. dollars, gross national income (GNI) in purchasing power parity (PPP), and population.

As shown, China's RPK per unit of GDP at official exchange rates is greater than those of Brazil, Japan, and Germany and over 80 percent of the U.S. ratio. When the PPP value of China's GNI is used, however, the Chinese ratio is significantly below those of the United States and Germany and roughly equivalent to those of Japan and Brazil. Thus, China's unusually high RPK/GDP ratio may be in part an artifact of an undervalued RMB. Nonetheless, the significant difference between the U.S. and Japanese ratios also suggests a range of possibilities for the development of Chinese air transportation. The difference between the U.S. and Japanese air markets and the direction in which China is likely to trend will be explored below.

Figure 2.7
Normalized RPK Flown by Major Carriers in Each Country in 2007



SOURCE: International Air Transport Association, 2008; World Bank Data Book, undated.

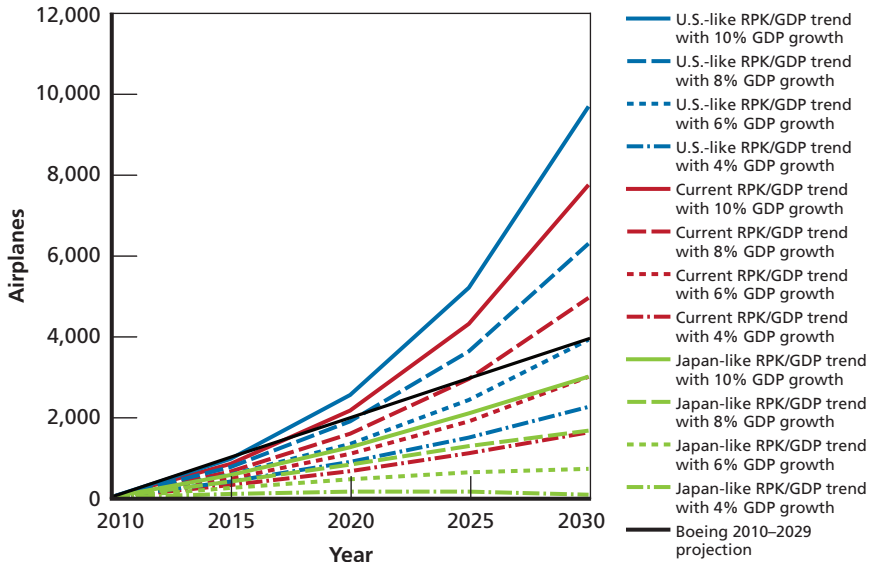
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China's future GDP growth is a much-debated issue. Many believe that China cannot indefinitely sustain its double-digit GDP growth rates or even its 8 percent GDP growth rate targets. We used a range of GDP growth rates (4, 6, 8, and 10 percent) over the next 20 years to bound our projections. Combining those four growth rates with three RPK/GDP trends (U.S.-like, current China, and Japan-like) produces 12 projections for the growth of the Chinese carrier fleet. They are plotted in Figure 2.8, along with a linear extrapolation of Boeing's 2029 projection. We assume that China's current fleet is relatively new and that very few current planes require replacement in the next 20 years.

Boeing's projection is equivalent to the current RPK/GDP ratio with an average 7 percent annual GDP growth for the next 20 years, or following a U.S.-like RPK/GDP trend with 6 percent GDP growth. Given the effects of compounding, 10 percent growth rates for 20 years and the current RPK/GDP ratio would result in fleet growth of almost

Figure 2.8

Projections of the Growth of the Chinese Commercial Fleet Based on Alternative RPK/GDP Ratios and Average GDP Growth Rates Compared with Boeing's Projection



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8,000 airplanes, more than double Boeing's projection. However, an average growth rate of only 5 percent of GDP at the current RPK/GDP ratio or 8 percent GDP growth but trending toward the Japanese RPK/GDP ratio would cut the 20-year projection to about 2,000 airplanes, half of Boeing's projection.

Factors Other Than GDP Growth

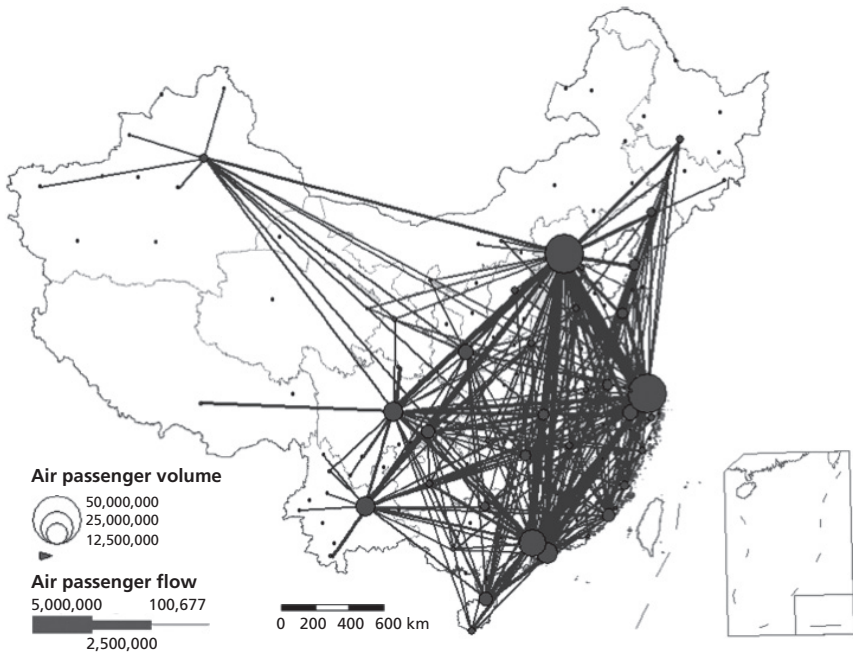
Wang and Jin (2007) assess major routes in China, using CAAC 2005 data. Between 1980 and 2005, the number of airports in China almost doubled, from 77 to 142. Annual passenger traffic grew from 3.4 million to 138.2 million passengers, or from 3.96 billion RPK to 204.5 billion RPK. In 2002, 62 percent of China's population was within 100 km of an airport, and 75 percent of China's GDP was generated within 100 km of an airport. In general, eastern China was better covered percentage-wise than western China, while central China lagged

behind both. The bulk of Chinese domestic routes are between 400 and 2,000 km in length, with concentrations around 600 km and 1,100 km, driven primarily by the concentration of air traffic in the Beijing-Shanghai-Guangzhou regional triangle. See Figure 2.9.

Jin et al. (2004) and Wang and Jin (2007) describe historical domestic flight patterns in China. The following key insights are found in both:

- The bulk of domestic passenger routes are in the range of 400 to 2,000 km.
- 50 percent of the total domestic travel is in a triangle connecting the greater metropolitan regions of Beijing, Shanghai, and Guangzhou.

Figure 2.9
Spatial Pattern of Domestic Air Passenger Flows in 2005



NOTE: Each line represents a route with at least 100,000 passenger trips.

SOURCE: Wang and Jin, 2007. Used with permission.

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The concentration of relatively shorter routes (400 to 2,000 km) would normally suggest greater demand for regional jets, which typically have shorter ranges. However, on a per-seat basis, regional jets are more expensive to operate than larger airliners. If there is sufficient passenger traffic to fill the seats, large commercial aircraft are more cost-effective. That fact, combined with the extreme concentration of passenger traffic in three metropolitan regions and the limited numbers of gates and departure/landing slots, drives the calculus back toward fewer larger airplanes. It might be thought that the Chinese government's focus on infrastructure projects and its ability to overrule red tape means that many new airports will be built, expanding the number of available landing slots. However, bureaucratic factors continue to complicate the expansion of airport infrastructure in China (Perrett, 2010a).

Another important issue is competition from rail and automotive transport. Traditional rail transport (less than 100 mph), in contrast to high-speed rail, is more cost-effective than air or automotive transport. India's extensive rail system helps explain why 98 percent of India's population has never flown ("Flight to Value," 2009). As the standard of living rises, however, the time cost of travel starts to outweigh the economic-cost advantage. This does not necessarily make rail uncompetitive with air travel, but it requires investments in high-speed rail, which in turn requires higher population densities for economic viability. For example, in Japan, high-speed rail competes directly with air travel, but in the United States, where the population is much less concentrated, high-speed rail is cost-effective only in certain areas (e.g., the Boston-New York City-Washington corridor). Given that China's population is highly concentrated and its governance structure is inclined toward funding major infrastructure projects, the development of high-speed rail that is competitive with domestic air travel, at least on shorter routes, seems likely (Perrett, 2010a).

In fact, high-speed-rail plans in China are quite extensive. According to the Chinese government's *Medium- to Long-Term Railroad Network Development Plan* (2008), China will construct approximately

16,000 km² of high-speed passenger designated lines (PDL) by 2020, with a targeted average speed of over 200 km/hr. These will include the eight PDL trunk lines in the so-called “four vertical, four horizontal (四纵四横)” national grid, in addition to shorter intercity commuter lines to be built in a number of major population centers.

The 4×4 national grid will consist of four north-south corridors and four east-west corridors. The north-south corridors will comprise the Beijing-Shanghai PDL, the Beijing-Wuhan-Guangzhou-Shenzhen-Hong Kong PDL, the Beijing-Shenyang-Harbin PDL, and the Hangzhou-Ningbo-Fuzhou-Shenzhen PDL (the Coastal PDL). The four east-west corridors will comprise the Xuzhou-Zhengzhou-Lanzhou PDL, the Shanghai-Nanchang-Changsha-Kunming PDL, the Qingdao-Shijiazhuang-Taiyuan PDL, and the Shanghai-Nanjing-Wuhan-Chongqing-Chengdu PDL. These lines will total roughly 13,000 km, with nearly 3,500 km already completed by mid-2010 (see Figure 2.10).

In addition, China plans to build approximately 3,800 km of high-speed intercity rail lines in about a dozen metropolitan areas, to add to the 500 km already in existence by mid-2010. These shorter commuter lines will average about 200 km each, with a design speed of around 250 km/hr. These lines can presumably offer residents of major metropolitan centers more options for airport access.

During the same period, the basic framework for the rail net in western China will also be completed, with the addition of 40,000 km of tracks. It is said that some of these new lines will be built to accommodate speeds of 200 to 250 km/hr for both passengers and freight. These are also considered high-speed rails, although they are not part of the primary PDL grid.

If all of these projects are completed as planned, by 2020, China will have more than 18,000 km of high-speed rail lines with speeds of 200 km/hr or more, accounting for more than 50 percent of the global total. With the exception of several major cities in the West (e.g., Urumqi, Lhasa), all provincial capitals will be reachable from Beijing by rail in less than 8 hours (“High-Speed Rail”) (see Figure 2.11).

Figure 2.10
High-Speed Rail Network in China

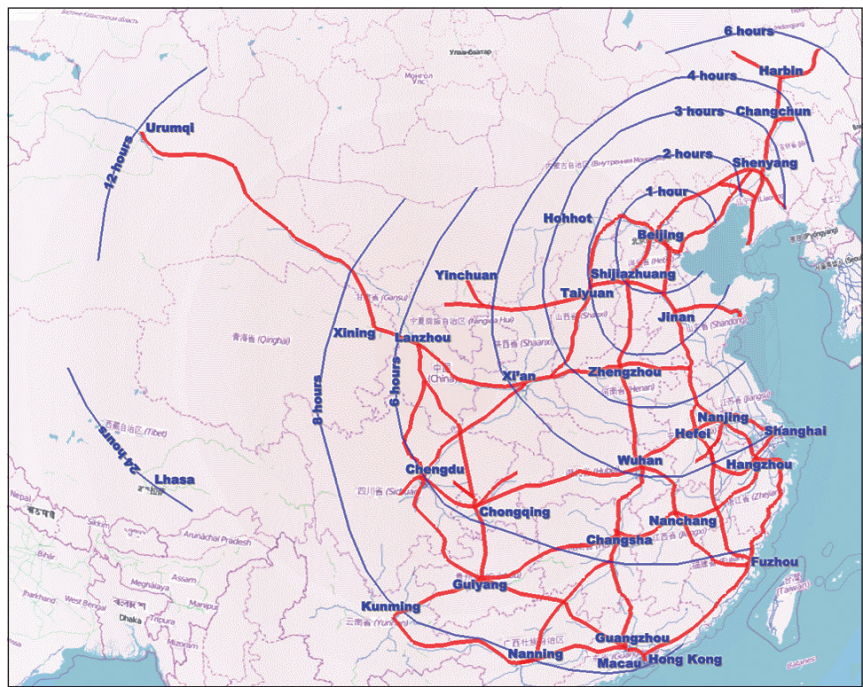


SOURCE: Ministry of Railways (China), Medium- to Long-Term Rail Net Planning Map—2008 Revision.

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High-speed rail is widely expected to pose a serious challenge to the airline industry, at least for travel between China's major coastal urban centers. As one analyst observes, the typical air travel time between Shanghai and Beijing, under normal weather conditions, is around 5 hours. This includes travel time to and from the airport, the time spent going through security checkpoints, boarding time, etc. On existing conventional trains, the trip would take 15 to 16 hours, but by express high-speed trains, it would take only 5 to 6 hours, roughly

Figure 2.11
Travel Time by PDL from Beijing to Selected Cities



SOURCE: China Central Television, undated.
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equivalent to the typical air travel time (Zhao, 1999). Likewise, travel time on the newly completed Wuhan-Guangzhou PDL is just under 3 hours, compared with a flight time of 1.5 hours for the 1,000-km trip.

While high-speed rail travel may offer some advantages in convenience and comfort, it is unlikely to offer any cost savings for the average Chinese traveler. A coach-class ticket between Wuhan and Guangzhou on the new high-speed train, for example, cost RMB490 (about \$72) as of August 2010 (“Ministry of Railways: High-Speed Train Fares Are Consistent with Market Conditions,” 2010).⁵ By compari-

⁵ Chinese railroad officials insist that these prices reflect actual market conditions and that traditional train fares were inexpensive only because they were heavily subsidized. See “Ministry of Railways: High-Speed Train Fares Are Consistent with Market Conditions,” 2010.

son, economy-class air fares between Wuhan and Guangzhou range from RMB370 for late-night flights to RMB470 for the early evening hours.⁶ The expensive fares of the new trains have undoubtedly discouraged many travelers—recent media investigations discovered some trains running with only a single passenger in a car (“Ministry of Railways Responds: How 120% Occupancy Rates Are Calculated,” 2010). However, much of the cost of rail transit, including trains and tracks, consists of sunk costs. Fares on lines that fail to attract significant passenger traffic will probably be reduced to increase traffic and recoup some of the sunk costs. In contrast, almost 90 percent of air travel costs are variable, and even the 10 percent fixed cost for airplane ownership is not fully sunk, because airplanes can always be sold (Belobaba et al., 2009, p. 115).

The ultimate impact of rail and expanding automotive transit systems on air traffic patterns is more complicated than simple competition between rail and air. Major hub airports located on a high-speed rail line might see shorter regional flights decrease as passengers use the rail line rather than the connecting regional jets to reach their ultimate destinations. On the other hand, airports not served by the high-speed rail will likely see additional growth in passenger traffic as local per-capita earnings rise.

Domestic Versus International Traffic

Another important dimension of the air transport market is domestic versus international traffic. Nations have complete regulatory power over domestic air traffic. Historically, domestic routes are flown only by domestic airlines, generally referred to as the Eighth and Ninth Freedoms under the Chicago Convention (Belobaba et al., 2009, p. 22). Even the Open Skies Agreement between the United States and the European Union (EU) applies only to international flights (Kanter and Clark, 2010). International route regulation is typically based on bilateral agreements and is structured with roughly equal landing rights, i.e., landing slots or airport access. As such, a country's international traffic is divided roughly evenly between domestic and foreign airlines.

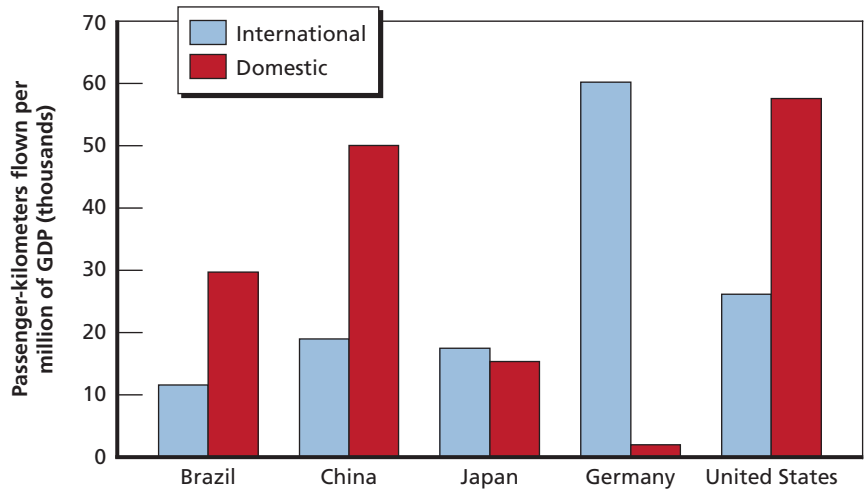
⁶ Fare information obtained via the Chinese travel reservation site 17u.cn.

As is the case with all nations, growth in Chinese domestic traffic will be completely absorbed by Chinese airlines, but international traffic growth will be split with foreign airlines. Figure 2.12 shows the distribution of international and domestic passenger traffic for Brazil, China, Japan, Germany, and the United States.

Very different patterns are evident in the figure. Germany's airlines serve international travel almost exclusively; presumably, most domestic travel in Germany is by rail or automobile. Japanese airlines provide roughly equal international and domestic service, which makes sense, as their island chain stretches more than twice the length of Germany. The United States, being a much larger geographic area, has longer routes and a much lower population density. Although it has a well-developed highway system, it has minimal rail service and essentially no high-speed rail. Thus, U.S. airlines fly two-thirds of their miles on domestic routes and one-third on international routes.

China's airlines deliver three-fourths of their service on domestic routes. China is a large geographic area similar in size to the United

Figure 2.12
International and Domestic RPK for Five Nations in 2007



SOURCE: International Air Transport Association, 2008.

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States, but its population density is both higher and much more concentrated, with more than 90 percent of the population living in the eastern half of the country. However, alternative transportation methods, rails and roads, are not as developed as those in Japan, Germany, or the United States, leaving Chinese citizens more dependent on air transport.

China's continuing development of rails and roads is likely to increase their competitiveness with air transport, which will limit the growth of domestic air transport. On the other hand, given China's vast expanses, rail travel is unlikely to replace air travel to the same extent that it has in Japan, and increasing per-capita income will likely result in more Chinese citizens traveling both domestically and abroad (especially if the Renminbi is allowed to strengthen). Thus, the net effect is that, in PPP terms, China's RPK/GNI ratio will likely increase to a level somewhere between those of the United States and Japan; and over the next two decades, China's air transportation market may continue to grow at a rate somewhat faster than the economy in PPP terms,⁷ but projections extrapolated from U.S. figures are likely to be overstated. In short, Boeing's projection appears reasonable, if we assume an average Chinese real growth rate of 7 to 8 percent over the next two decades.

⁷ Although GDP growth is typically measured in nominal terms, the uncertainty surrounding China's future exchange-rate policy makes projections in nominal terms inadvisable.

China's Current Commercial Aircraft Production

Essentially all aircraft manufactured in China, as well as major components such as engines and propellers, are produced by the Aviation Industry Corporation of China (AVIC) and Commercial Aircraft Corporation of China, Ltd. (COMAC) and their subsidiaries. AVIC was created in 1993 from portions of the former Ministry of Aerospace Industry (Medeiros et al., 2005, p. 157). In 1999, AVIC was split into two corporations, AVIC I and AVIC II, but, in 2008, they were recombined and COMAC was spun off as an independent corporation (Perrett, 2009, p. 313).

This chapter describes the current output of China's commercial aircraft industry, as well as aircraft that are in development. It does not attempt to analyze the organizations, inputs, or processes involved in China's production of commercial aircraft.

Commercial Passenger Aircraft

China currently produces two domestically designed commercial passenger aircraft: the MA60-series turboprop and the ARJ21 regional jet, which has not yet entered into service. China also performs final assembly on Airbus A320-series narrow-body airliners and produces the Embraer ERJ-145 regional jet under license.

Domestic Designs

MA60

The MA60 is a 60-seat turboprop airliner manufactured by the Xi'an Aircraft Corporation (XAC), an AVIC subsidiary. It traces its lineage

back to the Soviet Antonov An-24 airliner. The An-24, a 52-seat turboprop plane, entered into service with the Soviet airline Aeroflot in 1963. China subsequently purchased 40 of these aircraft and reverse-engineered them, with production beginning in 1982 under the designator Yun-7 (Y-7). The MA60 is simply an updated version of the Y-7, the previous version of which since 2001 has not met the CAAC's airworthiness requirements. The first prototype MA60 flew in March 2000, and the aircraft was certified for production in December of that year. An upgrade of the Antonov-built aircraft, called the An-24RV-100, was unveiled in 2001, but the MA60 does not appear to be based on this upgrade. According to Chinese official statements, 52 MA60 aircraft had been produced by September 2008, and as of March 2010, more than 150 orders had supposedly been placed, 50 from foreign airlines and more than 100 from domestic airlines. However, as of the end of 2009, only four examples appeared to be in service domestically. The first 11 production versions, moreover, had apparently been withdrawn from service by 2006 due to "reliability problems and two runway overruns." Production on an upgraded version (the MA60-100, sometimes called the MA600) began in 2008. XAC is said to have a production capacity of 12 to 15 of these aircraft a year ("XAC MA60"; "Antonov An-24"; "Xian (Antonov) Y-7"; "China Airlines Directory 2010," 2010).

ARJ21

The ARJ21 is a 90-seat regional jet that has been in testing since November 2008. The manufacturer, COMAC, partnered with Bombardier and based the design on the McDonnell Douglas MD-90, a few of which were co-produced in China in the 1990s. All the major subsystems are sourced to North American companies, including GE, Rockwell Collins, and Honeywell. The wings, the remaining most technically challenging aspect of an airplane, were designed by the Antonov Aeronautical Scientific/Technical Complex of Ukraine.

As of October 2010, the ARJ21 reportedly had 257 orders, with the first deliveries to Chengdu Airlines expected in late 2011. Virtually all of these orders are from small domestic Chinese airlines—Chengdu Airlines, Henan Airlines, Xiamen Airlines, Joy Air, and

Shanghai Airlines—and COMAC is actually the majority shareholder in Chengdu Airlines. There are questions, moreover, about how firm these “orders” are, as apparently some of them are actually letters of intent, and buyers reportedly face little or no penalty for cancellation. The Laotian national carrier, Laos Airlines, has ordered two ARJ21s, and the privately owned Indonesian mining company Merckuh Enterprises has reportedly signed a memorandum of understanding (MOU) to purchase nine. Over the next 20 years, COMAC hopes to build 850 ARJ21s, with production rates starting at 11 per year in 2010 and growing to 30 per year by 2015 (Burchell, 2010; Francis, 2010a; Shirouzu, 2010; Yeo, 2010; Francis, 2010c).

C919

The COMAC 919 will be a single-aisle 130- to 170-seat narrow-body aircraft intended to compete with the Boeing 737 and Airbus A320. The project was launched in 2009 with the goal of initial production in 2014 and sales by 2020 (Butterworth-Hayes, 2010, p. 27). Orders from China's “big three” airlines will be fewer than the several hundred units COMAC had initially hoped for. At the 2010 Airshow China in Zhuhai, COMAC announced that 100 C919s had been ordered, but this number was reached only by including nonbinding options. The “big three” each committed only to purchasing five C919s. Hainan Airlines ordered another 20, General Electric Commercial Aviation Services ordered 10, and the leasing subsidiary of China Development Bank ordered another 10. General Electric is one of the partners in CFM International, which will produce the engines for the C919, and China Development Bank is COMAC's financier. China's airlines have apparently argued that they should not take on more exposure to a program they regard as risky. Ultimate production goals for the C919 are 150 aircraft per year, to meet one-third of China's domestic demand and 10 percent of the international market. The program is reportedly heavily state-supported, and Chinese engineers are said to be getting paid twice the going rate to work on it (Perrett, 2010b, p. 49; Perrett, 2010c, p. 20).

Foreign Designs

A320

In September 2008, Airbus Final Assembly Line China (FALC), a joint venture between Airbus and a Chinese consortium of the Tianjin Free Trade Zone and AVIC to perform final assembly of Airbus A320-series aircraft, opened in Tianjin. It delivered its first A320 in June 2009 and as of August 2010 had delivered a total of 20 A320s and five A319s. The production rate is expected to increase to four aircraft per month by 2012. Unit production cost at the new assembly line is reported to be higher than that in Europe at present, although costs will likely decrease over time, but the facility is intended to produce aircraft only for the Chinese market (Ma, 2009). Thus, Airbus clearly established it as a vehicle for increasing its share of the Chinese market rather than to create a manufacturing cost advantage for itself.

ERJ-145

Harbin Embraer Aircraft Industry Company (HEAI), a joint venture between Embraer SA of Brazil and the Harbin Aircraft Industrial Group (HAIG), an AVIC subsidiary, was created in 2003 and delivered its first ERJ-145, 50-seat regional jetliner, in February 2004. However, the venture is said to have struggled from the start. Chinese airlines have been slow to place orders, and the orders that were received were often repeatedly postponed for various reasons. At one point, reports surfaced suggesting that the assembly line was facing closure (Ionides, 2006; Kirby, 2009). Despite a production capacity of 24 aircraft per year, the facility had delivered only 36 ERJ-145 aircraft as of August 2010, all to Chinese airlines (Ionides, 2006; "Embraer: Green Aviation," 2010; "HAIG—Harbin Aircraft Industries Group [Harbin Feiji Gongye Gongsi]," 2010).

Helicopters

All of China's current, ongoing helicopter programs are either collaborative projects with Western partners or derivatives of Western helicopters. The most important partners of the Chinese helicopter industry

include U.S.-based Sikorsky Aircraft, French-based Eurocopter, Italian AgustaWestland, and French engine-maker Turbomeca.

According to Wang Bin, the president of Avicopter, AVIC's helicopter subsidiary and builder of all Chinese helicopters, Avicopter will establish a new helicopter industrial base in Tianjin, as the "dragon-head" for other helicopter manufacturing centers such as Harbin and Jingdezhen. Tianjin will host Avicopter's top-level R&D facilities, as well as its sales and customer-support center. Existing manufacturing centers such as Changhe Aircraft in Jingdezhen and HAIG in Harbin will specialize in their respective areas of expertise. HAIG will specialize in composite-components manufacturing and assembly, and Changhe will specialize in digitized manufacturing and the drive train (Ma, 2009, pp. 23–24).

Avicopter's long-term ambition, according to Wang, is to establish a "unified, internationally competitive brand" for the Chinese helicopter industry. While establishing one's own brand does not preclude international cooperation, it does imply that "collaborative projects must conform to the product priorities and development strategies of Avicopter, and that they must contribute to the development of [Avicopter's] own brand." In particular, Wang warns against weakening Avicopter's branding strategy in the pursuit of short-term profits (Ma, 2009, p. 25). These remarks may suggest that Avicopter products will generally receive priority in resource allocation, even if co-production programs such as HAIG's Z-15/EC-175 project with Eurocopter may have more ready access to foreign markets.

Finally, it is worth noting that the production capacity of Chinese helicopter manufacturers remains rather limited at present. Changhe Aircraft—one of China's two major centers of helicopter production—has undergone steady expansion in recent years and expects to acquire the capacity to produce 30 light helicopters, 10 medium helicopters, and 15 heavy helicopters annually by 2012 (Yu, 2008, p. 67). For comparison, Bell Helicopter produces about 200 helicopters per year at its Mirabel plant alone ("About Bell Helicopter Textron Canada Limited," 2010).

Current Chinese helicopter programs are described below.

Z-8

The Changhe Z-8 is a medium transport helicopter developed from the French SA 321 Super Frelon, acquired by the People's Liberation Army (PLA) Navy in 1977–1978. Development of the Chinese copy of the SA 321 began in the late 1970s, but because of financial difficulties, first flight did not occur until December 1985. The model was not certified for design finalization until 1994. The Z-8 is identical to the Super Frelon in appearance, and the basic model is powered by three WZ-6 turboshafts (Chinese copies of the Turboméca 3C III), each rated at 1,512 hp (1,128 kW). Several dozen examples in at least six variants are serving in various branches of the PLA (“Zhi-8 Transport/SAR Helicopter,” 2009).

Z-9

The Z-9 series has been built by HAIG since the early 1980s and is possibly the most produced helicopter in China, with more than 200 aircraft delivered to both military and civilian customers. The original Z-9 was a license-built version of the Eurocopter AS365N Dauphin II twin-engine light utility helicopter. The Z-9B is an “indigenized” variant with 71.9 percent Chinese-made content. More than 150 Z-9Bs or its derivatives are believed to have been delivered to the PLA (“Zhi-9 Utility Helicopter,” 2009).

Z-11

The Changhe Z-11 is a 2,000-kg-class lightweight utility helicopter modeled after the French AS 350B Squirrel, with certain structural modifications. Development began in 1991, and first flight took place in late 1994. The design was finalized in 2000. The Z-11 is powered by a domestically produced WZ-8D turboshaft rated at 510 kW. Several variants have been developed, most of which have been produced for the PLA (“Zhi-11 Utility Helicopter,” 2007).

HC120/EC120 Colibri

The HAIG HC120/EC120 Colibri is a lightweight, single-engine helicopter developed by an industrial partnership comprising Eurocopter,

HAIG, and Singapore Technologies Aerospace. Development began in 1993, and first flight took place in 1997 (“HC120 Utility Helicopter,” 2007).

Mi-171 Family

Sichuan Lantian Helicopter Co., Ltd., in Chengdu, Sichuan, a joint venture established in 2007 with Mil Moscow Helicopter Plant JSC, assembles Russian Mi-171-series helicopters, including the Mi-171, Mi-17V5, and Mi-17V7, from kits. The Mi-171 series is a multirole medium-lift helicopter capable of carrying about 4,000 kg of payload. Under the initial contract, 20 helicopters will be assembled. This was originally to have been accomplished in 2008, but the first two helicopters were not delivered until December 2009. In a second stage of the program, 60 more helicopters will be produced (“SLHC—Sichuan Lantian Helicopter Company,” 2010; Grevatt, 2009).

Z-15/EC-175

The HAIG Z-15/Eurocopter EC-175 is a 6-ton-class medium utility helicopter co-developed by HAIG and Eurocopter as a 50-50 joint venture. Development began in 2006, and the first prototype made its first flight in 2009. Two assembly lines will be built, one in China and one in France (“Zhi-15 [EC 175] Medium Helicopter,” 2008).

AC313

The Avicopter AC313 is a triple-engine, 13.8-ton civil transport helicopter developed from the Z-8 military helicopter, itself a 1980s derivative of the Aerospatiale SA321 Super Frelon. Powered by three Pratt & Whitney Canada PT6B-67A turboshafts, it is the largest helicopter developed in China to date. First flight took place in March 2010 (Francis, 2010b). The AC313 makes extensive use of composite materials—roughly 50 percent by volume—and is equipped with a modern integrated avionics system (Peng, 2010, p. 15). Avicopter plans to certify the AC313 for the European and North American markets.

AC310

The Avicopter AC310 is a 1-ton, single-piston-engine light utility helicopter currently in development. No first flight has been reported (Wu, 2009, p. 21).

AC301A

The Avicopter AC301A is a two-ton, single-engine helicopter derived from the Changhe Z-11, with structural optimizations, an indigenous rotor system, an improved engine, and modernized avionics. The model is currently in development, and no first flight has been reported (Wu, 2009, p. 21).

Other

An unnamed heavy transport helicopter with an internal cargo capacity of 10 tons and an external carrying capacity of 13 tons is reportedly being designed. Development of this new helicopter is not expected to be completed until 2020 (Wu, 2009, p. 21).

Fixed-Wing General Aviation Aircraft

To date, developments in fixed-wing general aviation aircraft in China have been limited. China does not produce any business jets, and there is apparently no business jet program in development. As of late 2009, China had just under 800 fixed-wing general aviation aircraft, most of which appear to be light aircraft of foreign origin. For decades, fixed-wing general aviation aircraft in China were limited to Shijiazhuang Y-5s (copies of the An-2 Colt biplane) and Y-11s (a high-wing twin-piston-engine utility aircraft). China's first indigenously developed agricultural aircraft, the Hongdu N5A, did not make its first flight until 1989 (Qi, Xiao, and Xu, 2008, p. 18). Fixed-wing general aviation aircraft currently in production are described below.

Y-5B

The Shijiazhuang Y-5B, made by AVIC subsidiary General Aviation Co., is an updated variant of the Y-5 biplane, equipped with newer avionics and a more powerful engine.

Y-12

The HAIG Y-12 is a domestically designed high-wing twin-engine turboprop utility aircraft with a maximum takeoff weight of approximately 5,300 kg. The engines are made by Pratt & Whitney Canada. As of October 2009, at least 145 had been built, most of which were exported to countries including Iran, Kenya, Sri Lanka, and Zambia ("HAI Y-12," 2010).

N5

The Hongdu N5A is a single-seat agricultural aircraft with an effective payload of 900 kg. It is powered by a single Lycoming IO-720 piston engine and made its first flight in 1989. Only about 20 of these aircraft have been built. An improved version, the N5B, is powered by a Czech Walter M601F turboprop engine, which increases the plane's payload to 1,500 kg. The N5B made its official first flight in July 2008 ("HAIC N-5," 2010).

The Role of Foreign Firms in the Development of China's Commercial Aviation Manufacturing Industry

The aviation industry requires advanced, high-quality products that are produced at the minimum possible cost. Simply having cheap labor available is in most cases not sufficient to be competitive. The technologies for the most advanced products, such as turbine blades, composite materials, and complete integrated systems, are closely held by the companies that developed them. Designs and production technologies for other types of products may be more widely available or easier to develop, but here, the key is being able to produce them with sufficient precision, quality, and efficiency to be competitive.

Foreign firms have played an important role in the development of China's capabilities in these areas. The most basic role is simply providing a market for the products of China's aviation manufacturers. This gives them an opportunity to acquire the knowledge that comes from repeatedly manufacturing the same product (often referred to as "learning by doing") and from being forced to continuously improve quality and cost-efficiency in order to remain competitive, while being reimbursed for the cost of acquiring these skills (i.e., by selling their products to the foreign firms). If the price received exceeds manufacturing and delivery costs, any remaining profits can be reinvested in acquiring the capability to produce new products or in improving the quality or production efficiency of existing products. In some cases, the foreign purchaser may also provide more direct assistance in manufacturing technology or quality control.

Manufacturing and R&D joint ventures provide additional opportunities for Chinese firms to learn. In a manufacturing joint venture, the foreign partner typically supplies the production design and management expertise, while the Chinese partner provides the facility and labor. Thus, the Chinese partner has an opportunity to learn how to efficiently produce a line of products it was previously unable to produce. The drawback of manufacturing joint ventures is that they are often effectively controlled by the foreign partner, which limits the Chinese partner's ability to steer the venture toward product areas that are of interest to the Chinese parent (or to use the product to supply clients in China's defense sector).

An R&D joint venture provides an opportunity for the Chinese partner to learn not only how to produce a specific line of products, but also how to design and develop entirely new lines of products. Thus, from the perspective of the Chinese partner, R&D joint ventures provide the greatest opportunity to assist the growth of its production capabilities.

Foreign firms can also assist the development of China's aviation manufacturing capabilities by being acquired by Chinese aviation companies. The acquiring Chinese firm theoretically has access to all of the foreign firm's manufacturing technology and R&D capabilities. However, transferring these capabilities to the Chinese parent may present practical challenges, including technology export restrictions in the home country of the foreign firm.

Many aviation technologies are inherently dual-use. Thus, to the extent to which foreign firms are contributing to the capability of Chinese companies to produce civilian aviation products, they are also contributing to China's capability to produce military products. These military products could include whole systems, such as transport aircraft or utility helicopters, or important subsystems and components. In addition, although North American and European countries restrict the transfer of weapons technologies to China, the restrictions vary by country. This variability has enabled China to acquire from other countries technologies that the U.S. government would not have allowed American companies to transfer. Specific examples include Eurocopter's assistance to China in developing the rotor system for a new heli-

copter that was later determined to have assisted in the development of a new attack helicopter, and Turbomecca's collaboration with AVIC to develop a turboshaft engine for a military transport helicopter, thus avoiding a potential U.S. embargo on the Pratt & Whitney engine the helicopter was originally designed to use.

There is no question, therefore, that foreign involvement in China's aviation manufacturing industry is contributing to the development of China's military aerospace capabilities. There is also little doubt that this is a deliberate policy of the Chinese government. This is not to say that encouraging foreign involvement in China's aviation manufacturing industry is simply a ruse to facilitate the development of China's military aerospace industry. Rather, encouraging foreign involvement in China's aviation manufacturing industry serves two equally important purposes for the Chinese government: (1) it facilitates the development of a highly valued commercial sector, as part of China's economic development strategy, and (2) it aids the development of China's military aerospace industry.

Chinese Government Policies Toward Foreign Aviation Manufacturing Companies

International aerospace sales historically have involved not just the participating firms, but also the governments of the countries in which they are based. Many airlines are owned and operated by governments, and national governments, even in nominally free-market countries such as the United States, see it as their responsibility to promote the overseas sales of their nations' products, particularly high-value-added goods such as airliners. Deregulation and market competition have diminished the government's role in aircraft sales but certainly have not eliminated it.

Japan is a prime example of government influence on airplane sales. Since the 1970s, the Japanese government has subsidized three Japanese manufacturers—Mitsubishi, Fuji, and Kawasaki Heavy Industries—in taking on growing roles as major suppliers to Boeing, producing 15 percent of the 767, 22 percent of the 777, and 35 percent

of the 787 (Newhouse, 2007, pp. 28, 171–172). This has involved the transfer of significant wing design experience and composite technology. Boeing has greatly benefited from the arrangement, with the dominant share of large commercial aircraft sales to Japan, access to low-cost capital, and risk-sharing with the three Japanese manufacturers (Newhouse, 2007, p. 61).

Airbus, itself, was predicated on the distribution of design and manufacturing efforts across companies from the four original national partners: France, Germany, Great Britain, and Spain (Morrison, 2010). Historically, national carriers in the same four countries purchased primarily Airbus planes, but aviation deregulation and low-cost carriers have diversified the EU market for large commercial aircraft. Further, work or technology distribution is difficult for Airbus, as it has to balance that with the interests of the four major partner nations (Karp, 2007).

Recognizing that its aerospace industry is not yet capable of designing and producing large commercial aircraft that are competitive with modern Airbus and Boeing products, China's government has allowed its airlines to import such aircraft since the 1980s. However, the Chinese government has also used the purchase of large commercial aircraft to pursue other goals. In the past, for example, the Chinese government has suggested that large orders for Boeing planes hinged on the renewal of Most Favored Nation trading status (Newhouse, 2007, pp. 182–183). More recently, Beijing has suggested that Boeing's success in China may be jeopardized by political friction over Taiwan (Heim, 2005). In addition, China's central government, with hopes of modernizing its aerospace industry, has attempted to leverage large commercial aircraft purchases in exchange for arrangements that it hopes will lead to technology transfer. Tempting airplane manufacturers with the huge potential market in China, the Chinese government has encouraged producers of large commercial aircraft to establish manufacturing and assembly joint ventures with state-owned aerospace corporations. Often, this has taken the form of domestic assembly or subcomponent production, e.g., the McDonnell Douglas MD-80/90 assembly agreements and past Boeing component contracts. The technology transfer associated with these arrangements,

however, was limited to manufacturing and production methods. The same is true of the much-touted Airbus final assembly line recently opened in Tianjin. According to industry reports, all major parts are manufactured at Airbus's plant in Hamburg and shipped to Tianjin only for final assembly (Francis, 2008).

Since the late 1990s, therefore, the Chinese government has encouraged joint ventures with the hope of increasing technology transfer. These policies have been only partially successful, however. Most of the aviation joint ventures established in China have involved older systems and still consist primarily of assembly operations. Key technologies and components such as engines or avionics are manufactured in the West and imported into China for assembly. It should also be pointed out that while technology transfers of this type do help to elevate China's commercial aerospace capabilities from a very low base, their direct impact on Chinese military capabilities is even more limited, as the most critical military aerospace technologies are unlikely to be transferred via commercial avenues. Stealth, for instance, is not directly relevant to commercial aviation, and the same is true for sensor fusion and networking multiple aircraft. Basic engine technology is common to both commercial and military aircraft, but design goals for affordable, highly efficient commercial turbofans are quite different from those for high-performance military engines.

Nonetheless, by their very nature, joint ventures offer a potential mechanism for evading U.S. export controls, and although the majority of joint ventures between Western aerospace corporations and Chinese entities to date have been in civilian areas with limited military relevance, the possibility clearly exists for technology transfers of a more military character. The Chinese certainly appear highly conscious of the military implications of various ventures. Thus, while projects of a predominantly civilian nature are generally handled on commercial terms, those of more significant dual-use value are conducted with greater attentiveness to China's security objectives. For example, for its Z-15/EC-175 medium utility helicopter project with Eurocopter, China is currently working on replacing the aircraft's original Pratt & Whitney engine with a domestically produced model jointly developed

with Safran Turbomeca, reportedly as a hedge against possible U.S. sanctions once the helicopter enters PLA service (Morris, 2010).

In addition, the technology level of Western aerospace joint ventures in China has increased steadily over time. China has arguably taken a new approach with its ARJ21 regional jet and C919 airliner projects. While both programs involve significant outsourcing to U.S. and EU suppliers for advanced components such as engines and avionics, a condition for being selected as a supplier is often that a joint venture with a local partner be set up and local production facilities be established (Mecham and Anselmo, 2010). These new ventures may bring with them significantly newer technologies.

Although Western aerospace companies are generally tight-lipped about the details of their China strategies, and the specific contents of commercial agreements are rarely divulged, a correlation between major aircraft sales and local subcontracting clearly exists, suggesting that offset arrangements are indeed a major consideration in many deals. In this regard, the competition between Boeing and Airbus is the most visible and instructive. In 1995, Boeing held a commanding lead over Airbus in the Chinese market, accounting for roughly 60 percent of the Chinese commercial fleet and more than 80 percent of all new orders ("China and Boeing Partnership Delivering Value," 1995), while Airbus held a mere 7 percent market share with only 29 planes sold ("Airbus in China," 2010). By 2010, however, Airbus's market share had risen to over 43 percent, while Boeing's share had fallen to roughly 55 percent (World Aerospace Database). In media interviews, industry experts rarely discuss the role of offsets in the competition between Boeing and Airbus, pointing instead to factors such as the lack of Chinese cultural and linguistic expertise at senior levels of Boeing management, Boeing's sometimes short-sighted preoccupation with cost control, Boeing's perceived complacency in customer relations, and even the entry-visa difficulties experienced by Chinese airline executives after the 9/11 attacks. For its part, Boeing management dismisses the Chinese complaints as routine disagreements between buyers and sellers and attributes Airbus's success to its strategy of "flooding the market with surplus production at discount prices" (Heim, 2005).

All of the factors discussed above probably play a role in success in the Chinese market, but the key appears to be an aggressive program of local production. For example, in 2005, a group of Chinese airlines contracted with Boeing to purchase up to 60 Boeing 787 Dreamliners, a deal worth \$7.2 billion at nominal list prices (Gates, 2005). Later the same year, it was announced that Boeing had selected a number of Chinese manufacturers as suppliers to the 787 program, including several single-source contracts on some of the largest components awarded to a Chinese supplier to date. In all, Boeing sold a total of 117 aircraft to Chinese airlines that year, making 2005 Boeing's most successful year in China to date ("Orders and Deliveries—User Defined Reports").

That same year, however, Airbus secured an order for 150 A320 airliners from China in a deal valued at close to \$10 billion ("Airbus in China," 2010). It was subsequently revealed that Airbus had reached an agreement with China to establish its first final assembly line outside of Europe in Tianjin, and Airbus was rewarded with a contract for another 150 A320s and 20 A350s in 2006. In 2007, French President Nicholas Sarkozy returned from a state visit to China with the largest Airbus order from China to date, a \$17.4 billion contract for 110 A320s and 50 wide-body A330s. Most recently, Chinese president Hu Jintao concluded another agreement with Airbus during his November 2010 state visit to France, an order for 50 A320s, 42 A330s, and 10 A350s valued at \$14 billion, with half of the A320s to be assembled in China (Fouquet and Viscusi, 2010). By comparison, during the same period (2006–2010) Boeing sold a total of only 287 airliners in China ("Orders and Deliveries—User Defined Reports").

In conclusion, Chinese government leverage over large commercial aircraft sales has caused Boeing and Airbus to transfer older production and assembly technology to China, but no Chinese companies are yet Tier 1 suppliers to Boeing or Airbus. To increase technology transfer, COMAC is partnering and establishing joint ventures with many Western companies through the ARJ21 and C919 projects. However, those Western companies have a vested interest in maintaining control of their core intellectual property, which likely explains why most of the technologies planned for the C919 are, with a few

exceptions, already currently deployed in modern airliners (Mecham and Anselmo, 2010).

It should also be pointed out that the interests of Chinese state-owned enterprises are not identical to those of the Chinese government. This is most obvious in the case of China's state-owned airlines, which have resisted large-scale commitments to the ARJ21 and C919 despite the central government's desire to establish COMAC as one of the world's leading manufacturers of regional jets and airliners. Similarly, AVIC has been pursuing its own jet transport projects, which would compete with those of COMAC.

Joint Ventures and Cooperative R&D Activities

Joint ventures with foreign enterprises came relatively late to the Chinese aviation industry. The first joint venture in this sector was established in 1996, when Pratt & Whitney partnered with the Chengdu Engine Group Company to establish a production facility in Chengdu to produce components for aircraft engines and industrial gas turbines. The initial investment was only \$25.1 million. Since that time, however, foreign investment in the Chinese aviation sector has expanded rapidly, and today most major Western commercial aircraft manufacturers and aviation subsystems suppliers have established joint ventures in China.

Joint ventures are frequently regarded as an effective vehicle for Western companies attempting to gain access to the Chinese market. Certainly, Chinese aviation industry leaders have made no secret of their desire to trade market access for technology, and joint ventures are their vehicle of choice for gaining access to advanced Western technologies. Naturally, partnerships in technological areas of particular concern to the Chinese have received the highest priority. One such area is aircraft engines: The earliest joint ventures in the aviation sector, spearheaded by Pratt & Whitney, were with engine component producers. Since then, both GE and Rolls-Royce have established joint ventures in China and greatly expanded local procurement. Another area is composite-materials manufacturing techniques. Both Boeing

and Airbus have established joint ventures specializing in composite components, and Airbus has recently transferred the technology for manufacturing the entire composite wing of the A320 airliner to its joint-venture composite manufacturing center in Harbin.

It should be noted, however, that joint ventures *per se* do not guarantee effective market access. Those that do not provide access to coveted technologies or—even more problematically—are perceived to compete against domestic producers are not likely to receive preferential treatment and may indeed face severe obstacles. In this regard, the case of Embraer's joint-venture production line in China can be instructive. Established in 2003, the venture is said to have struggled from the start. Chinese airlines were slow to place orders, and many of the orders that were received were repeatedly postponed for various reasons. Despite a production capacity of 24 aircraft per year, the facility had delivered only 36 ERJ-145 aircraft as of August 2010. Embraer's lack of success is likely related to the anticipated arrival of COMAC's ARJ21 regional jet, which has undoubtedly influenced the procurement decisions of Chinese airlines, as they expect to be required to place orders for the ARJ21.

It is also worth noting that Western aerospace companies have been generally cautious about transferring advanced technology to China or setting up joint ventures in critical areas. However, a turning point may have been reached with the COMAC C919 project. Unlike the ARJ21 program, which has sourced directly from Western suppliers, COMAC management has made it explicitly clear that foreign bidders on the C919 program are expected to form joint ventures with Chinese partners, especially in high-technology areas such as advanced materials and flight control systems, where Chinese technology is lagging. In areas of less concern, the Chinese are content with traditional subcontracting or other work-share arrangements, although according to COMAC Deputy General Manager Wu Guanghui, local production is considered a minimum requirement for foreign suppliers to the C919 program (Zhang, 2010, p. 34).

In response, a whole spate of new joint ventures has been announced between Western aerospace suppliers and AVIC subsidiaries, the most notable of which is the joint venture between CFM

(itself a joint venture between GE and Snecma of France) and AVIC Commercial Aircraft Engines Co. (ACAE) to assemble the LEAP-X1C engine in Shanghai. ACAE is said to have started building a \$472 million R&D center in Shanghai and hopes to start building “homegrown engines” (presumably a locally produced version of the LEAP-X) for the C919 in 2016. Every C919 contract awarded to a foreign bidder has been awarded to a joint-venture entity. And a number of companies that had not established manufacturing joint ventures in China—including Nexcelle, Goodrich, Parker Aerospace, Rockwell Collins, and Liebherr—have recently entered into joint-venture agreements in connection with their C919 bids. A summary of international partners in the ARJ21 and C919 programs is provided in Tables 4.1 and 4.2.

Detailed information regarding major current and prospective joint ventures and cooperative R&D activities between Chinese and foreign companies that we were able to identify is provided below.

U.S. Companies

Alcoa, Inc.

According to an October 2009 announcement, Alcoa and COMAC are “jointly exploring” technology solutions for the design and development of the C919. Through a technology cooperation agreement, the two companies are examining advanced aluminum structural concepts, designs, and alloys for the new aircraft (“Alcoa and COMAC Explore Leading Technology Solutions for C919, China’s Largest Passenger Aircraft,” 2009).

The Boeing Company

Boeing China, Inc., is based in Beijing. It includes representatives of Boeing organizations such as Government Affairs, Commercial Airplane Sales, Marketing, Business Development, Commercial Aviation Services, Altheon, Jeppesen, and Communications. As of October 2009, there were 150 Boeing employees in China and more than 6,100 employees at Boeing-related businesses (subsidiaries and joint ventures) (Fetters-Walp, 2009, p. 13).

Table 4.1
International Partners in the ARJ21 Program

ARJ21 Program Partners	Contribution
U.S. Partners	
Alcoa, Inc.	Advanced alloys for airframes, wing and fuselage stringers, floor beams, seat tracks; fasteners and miscellaneous structural components
B/E Aerospace, Inc.	Oxygen equipment
Eaton Corporation	Flight-deck instrument panel and lighting controls
General Electric	Propulsion (engines, nacelles, and accessories)
Goodrich Hella Aerospace	Lighting equipment
Hamilton Sundstrand	EPS/high-lift/auxiliary power unit (APU)
Honeywell International	Flight control system integration and synthesis
Kidde Aerospace (Hamilton Sundstrand subsidiary)	Fire protection
MPC Products Corporation	APU, door system
Parker Aerospace	Fuel, hydraulic, and electrical flight controls
Rockwell Collins	Integrated avionics system (Proline 21)
Rosemount, Inc. (Emerson subsidiary)	Windshield wiper and heater
Zodiac Air Cruisers Company	Emergency evacuation system
Non-U.S. Partners	
Antonov ASTC (Ukraine)	Wing design, structural strength analysis
Avio-Diepen (Netherlands)	Material management
CAE Inc. (Canada)	Full flight simulator
Fisher Advanced Composite Components (Austria)	Cockpit, cabin interior, kitchens, restrooms
Liebherr Aerospace Toulouse (France)	Air management system
Liebherr Aerospace Lindenberg (Germany)	Landing-gear braking system
Meggitt Vibro-Meter SA (Switzerland)	Engine interface control unit, engine vibration monitoring system
Safran Sagem (France)	Flight-deck control suite
Saint-Gobain Sully (France)	Windshields and opening windows
Zodiac Evac Vacuum Systems, Shanghai	Water/waste
Zodiac Sicma Aero Seats (France)	Crew seating

SOURCE: AVIC I Commercial Aircraft Company, Ltd., undated.

Table 4.2
Major International Partners in the C919 Program

C919 Program Partners	Contribution
U.S. Partners	
Eaton Corporation	Pipelines for fuel and hydraulic systems
General Electric	Propulsion (CFM International); engine nacelle, thrust reversers (Nexcelle); avionics system core processing and display; onboard maintenance and flight data recording
Goodrich Corporation	Exterior lighting; landing gear and engine nacelle components
Hamilton Sundstrand	Electric power generation and distribution; cockpit pilot controls (side sticks, pedals, etc.)
Honeywell International	Flight control system; APU; wheels and tires, braking system; inertial reference and air data systems
Kidde Aerospace (Hamilton Sundstrand subsidiary)	Fire and overheat protection systems
Parker Aerospace	Fuel and hydraulic systems
Rockwell Collins	Communication and navigation systems; integrated surveillance system; cabin core system
Non-U.S. Partners	
Fisher Advanced Composite Components (Austria)	Cockpit, cabin interior, kitchens, restrooms
Liebherr Aerospace Toulouse (France)	Air management system
Liebherr Aerospace Lindenberg (Germany)	Undercarriage system

SOURCE: Various media reports.

Boeing has the following joint ventures in China:

- 9-percent interest in Taikoo Aircraft Engineering Co., Ltd. (TAECO), Xiamen, an aircraft maintenance, conversion (passenger to freighter), and repair facility with more than 5,000 employees.
- 60-percent interest in Boeing Shanghai Aviation Service Co., Ltd. (BSAS), a joint venture with Shanghai Airlines (15 percent) and the Shanghai Airport Authority (25 percent). BSAS performs passenger-to-freighter conversions; upgrades to interiors, avionics, and entertainment systems; line maintenance; and heavy main-

tenance checks. Construction of the facility began in 2007 with an initial total investment of \$85 million. The company has more than 120 employees.

- 88-percent interest (expanded from 40 percent after Boeing bought out former joint-venture partner Hexcel and made additional investments) in Boeing Tianjin Composites Co., Ltd., Tianjin, a joint venture of Boeing and AVIC for secondary composite structures and interior parts for the full range of Boeing aircraft. First deliveries started in 2002. In 2008, Boeing invested an additional \$21 million in facility expansion, doubling the size of the original plant and increasing its production capacity by 60 percent. The new plant will employ roughly 1,000 workers (“Boeing Tianjin Composite Materials Facility Undergoes Expansion,” 2008, p. 9).

In addition to the subcontracting and joint-venture activities described earlier, Boeing provides technical expertise and international operational experience in aviation safety, efficiency, reliability, and quality to Chinese airlines, regulatory authorities, and industry. This technology transfer helps ensure flight safety, reliability, and efficiency and the production of safe, high-quality airplane hardware. Boeing directly supports CAAC in its development of International Civil Aviation Organization–compliant aviation laws for China, civil aviation regulations, and various safety enhancement plans. Boeing works with CAAC on advanced air traffic systems to enhance the safety and efficiency of China’s air traffic system. Some specific projects include the development of a Federal Aviation Administration (FAA)–style training center for flight and maintenance inspectors; the development of CAAC’s automatic dependent surveillance–broadcast (ADS-B, a cooperative surveillance technique for air traffic control) implementation plans; and a number of Required Navigation Performance demonstration flights into high-altitude airports in Tibet (“Dawn of a New Age,” 2010).

In addition, Boeing has reportedly provided professional training worth several hundred million dollars to more than 37,000 Chinese aviation professionals since 1993, at no charge to China. An executive development program for senior CAAC and Chinese airline managers

was launched in 1998 and is still ongoing. Annual senior executive development programs have also been conducted for Chinese aviation industry executives from AVIC. Other training programs supported by Boeing include the Boeing Masters of Business Administration (MBA) program for junior and mid-level officials from the Chinese aviation sector and a three-year internship program launched in 2008 for 60 Boeing Fellows, half from the United States and half from China (“Boeing’s Investments in China,” 2010).

Boeing is also a leading participant in the U.S.–China Aviation Cooperation Program (ACP), a partnership of CAAC, the U.S. government, and various American aerospace firms launched in 2004. The program conducts executive development, energy conservation seminars, flight standards programs, and various other training programs for Chinese aviation sector personnel. Boeing has also established a number of training and technology development programs in partnership with several Chinese universities (“Boeing’s Investments in China,” 2010).

Eaton Corporation

Eaton has the following joint ventures in China:

- 49-percent interest in a new joint venture with Shanghai Aircraft Manufacturing Co., Ltd. (SAMC), a COMAC subsidiary, announced in July 2010 (“Eaton Corporation and Shanghai Aircraft Manufacturing Co., Ltd. Announce a Joint Venture,” 2010). The project will be based in Shanghai and will focus on the R&D, production, and support of fuel and hydraulic conveyance systems for the COMAC C919 program and the global civil aviation market in general. Total program value for the C919 project, including aftermarket opportunities, is estimated at \$1.8 billion, based on an anticipated volume of 2,500 aircraft. The joint venture is the first for a COMAC enterprise with a foreign company.
- 51-percent interest in Eaton Electrical (ZhongShan) Co., a joint venture with MingYang Electrical Appliances Co., located in Zhongshan, Guangdong. Established in 2005, the joint venture produces medium-voltage switchgear, electrical automation, and

protection products (“Eaton Signs Joint Venture Agreement with MingYang for Medium-Voltage Switchgear Components,” 2005).

- 55-percent interest in Eaton Senstar Automotive Fluid Connector (Shanghai) Co., a joint venture with Changzhou Senstar Automobile Air Conditioner Co., Ltd. Established in 2004, the venture produces various air-conditioning and power-steering components (“Eaton Plans Joint Venture with Changzhou Senstar Automobile Air Conditioner Co., Ltd. in China,” 2004).
- Unspecified interest in Shanghai Eaton Engine Components Co., a three-partner venture with Nittan Valves of Japan and Huamu Township near Shanghai. Formed in 1998, the firm produces engine valves and hydraulic lifters.

In addition, Eaton is engaged in various collaborative research projects with Chinese universities and research institutions. In 2008, Eaton established a global R&D center in Suzhou, one of its three global R&D centers. The Eaton Suzhou Center was initially staffed with 100 researchers, and the number was expected to increase by 40 percent by 2010. The product design team was to engage in the R&D of vacuum circuit-breakers, medium-voltage components and systems, switchgears, uninterruptable power supplies, industrial control products, etc. (“Eaton Electrical Suzhou New Facility to Operate as Global R&D Center,” 2008).

GE Aviation

GE has the following joint ventures in China:

- 51-percent interest in GE Engine Services (Xiamen) Co., Ltd., a joint venture with a Chinese consortium led by China Eastern Airlines (30 percent) and Hainan Airlines (10 percent). The facility, which began operations in 2001, provides maintenance, repair, and overhaul (MRO) services for the CFM56 family of jet engines. The joint-venture structure is notable in that China Eastern provided no initial investment for its 30-percent share except an agreement to service its engines at the facility (“GE Engine Services Opens Engine Overhaul and Repair Facility in Xiamen,

China," 2001; "The Last Kilometer: GE Scrambles for the Chinese Market," 2001).

- 50-50 prospective joint venture between Nexcelle and AVIC Aircraft announced September 2009. Nexcelle is the nacelle joint-venture company created by GE's Middle River Aircraft Systems and Aircelle, a Safran group company, while AVIC Aircraft is engaged in the development of medium/large transport aircraft, small commercial aircraft, and landing-gear systems and nacelles in China. The new venture will design and manufacture engine nacelles and components for the COMAC C919 as well as other existing aircraft ("AVIC Aircraft and Nexcelle Announce Plans for a Nacelle Joint Venture in China," 2009).
- 50-percent interest in a prospective joint venture with AVIC Systems, announced in November 2009, to develop the integrated avionics system for the COMAC C919. The new avionics company will offer fully integrated, open-architecture avionics and services for future commercial aircraft programs. Although it will be headquartered in China, GE claims that the new venture will create about 200 jobs in the United States ("GE and AVIC Joint Venture Creates New Global Business Opportunities," 2009). While many analysts consider the venture to be risky given GE's lack of experience in the area, it is also regarded as a "huge deal [of the type] that has the potential to redefine the avionics market once every 15 to 20 years" (Layne, 2010).
- Undetermined interest in a prospective joint venture between CFM and ACAE, announced in December 2009, to establish a final assembly line and engine test facility for the LEAP-X1C engine selected for the COMAC C919 airliner. ACAE and CFM have reportedly established a working team to evaluate the scope and feasibility of the project. This same team will formulate the business plan and develop the legal structure and operating agreement for the proposed joint venture ("CFM and ACAE Sign MOU for LEAP-X1C Assembly Line In China," 2009). For CFM, the C919 contract is reportedly valued at \$5 billion and may be worth up to \$15 billion over the next 30 years ("CFM Picked to Power China's Future Plane," March 2010).

In addition, GE Aviation has been very active in training technicians from Chinese airlines on GE engine technology and line maintenance needs. In 1996, GE and CFM partner Snecma opened a \$17 million aero engine maintenance training center in Guanghan, Sichuan, adjacent to the CAAC Civil Aviation Flying College. The training center was the first of its kind in China and the third such GE facility—the other training centers are in Cincinnati and Melun-Montereau, France. The curriculum offered is reportedly identical to that at GE's other training facilities ("Aero Engine Maintenance Training Center Opens in Guanghan," 1996). By the end of the 2000s, GE was training hundreds of Chinese jet engine technicians annually. In 2008, for instance, more than 500 flight-line mechanics and propulsion engineers from almost 20 Chinese operators received training in flight-line engine maintenance, engine removal and installation, and engine borescope procedures. The training occurred at the Guanghan facility and at GE's Customer Technical Education Center in Cincinnati. It is said that Chinese airlines routinely send a dozen or more technicians at a time to spend at least two weeks at the Cincinnati facility ("GE Training Hundreds of Jet Engine Technicians from Chinese Airlines," 2008).

Goodrich Corporation

Goodrich has the following joint ventures in China:

- 51-percent interest in Goodrich Asia-Pacific Limited, a Hong Kong-based joint venture launched in 1993 with the Hong Kong Aircraft Engineering Co. (HAECO), a subsidiary of the Swire Group. The company provides carbon-brake heat-sink refurbishment and wheels/brakes repair/overhaul services to commercial aircraft ("Goodrich Asia-Pacific Limited [GAP]").
- 65-percent interest in Goodrich TAECO Aeronautical Systems (Xiamen) Co., Ltd., a Xiamen-based joint venture formed in 1994 with the Taikoo Aircraft Engineering Co., itself a joint venture between HAECO, the Xiamen Aviation Industrial Park, and several airlines in the region. Goodrich TAECO is an MRO facility for engine and flight-control systems, electrical power generation,

and other aerospace equipment ("Goodrich TAECO Aeronautical Systems").

- 50-percent interest in each of two prospective joint ventures between the Xi'an Aircraft International Corporation (XAIC) and Goodrich Landing Gear and Goodrich Aerostructures, according to an August 2009 agreement. The joint-venture companies will support landing-gear and engine-nacelle components manufacturing for the COMAC C919 program and will also supply components for other aircraft ("Goodrich and China's XAIC Agree to Form Joint Venture Companies," 2009).

Hamilton Sundstrand

Hamilton Sundstrand has the following aviation-related joint ventures in China:

- 65-percent interest in Qinling Aerospace, Ltd., a Xiamen-based joint venture with Shaanxi Aero-Electric Co. launched in 2000. The company provides overhaul and repair services for Hamilton Sundstrand power systems to Chinese airlines ("China Locations").
- Unspecified interest (believed to be approximately 50 percent) in a prospective joint venture with AVIC Systems Co., announced in April 2010, to develop and manufacture the electrical system for the COMAC C919 program. Hamilton Sundstrand values the deal at more than \$1 billion in revenue over the life of the program ("Aerospace Firm Wins C919 Deal," 2010).

Honeywell Aerospace

Honeywell has the following joint ventures in China:

- 65-percent interest in Honeywell TAECO Aerospace (Xiamen) Co. (HTAC), a joint venture launched in December 1995 with HAECO and Taikoo Aircraft Engineering Co. The company provides MRO services for GTCP85- and GTCP331-APUs, APU accessories, pneumatic valves, and components such as heat

exchangers and avionics equipment to airlines operating in China (“Honeywell TAECO Aerospace (Xiamen) Co., Ltd.”; “Review of Operations”).

- Unspecified interest in the CEA Honeywell Aircraft Wheels and Brakes Repair and Overhaul Co., a joint venture with China Eastern Airlines launched in December 1995. The company specializes in MRO services of aircraft wheels, brakes, and other related components, as well as carbon-brake refurbishment (“Aerospace”).
- Unspecified interest in CRIAA Honeywell (Nanjing) Aero-Accessories Co., a joint venture launched in April 1997 with AVIC subsidiary China Research Institute of Aero Accessories (CRIAA) with an initial investment of \$11.7 million. The company develops and produces commercial aircraft environmental control systems (ECS) for the domestic and export markets and produces aircraft parts for export, including Boeing 737 high-temperature-alloy heat-exchanger flanges and pressure-sensor bosses and aluminum duct assemblies for Boeing 737 and 757 aircraft (“Aerospace”; “CRIAA Honeywell: We Compete Only Against Ourselves”).
- 50-percent interest in a prospective joint venture with AVIC subsidiary Flight Automatic Control Research Institute (FACRI) to supply the fly-by-wire control system for the COMAC C919, announced in July 2010. According to Chinese reports, the new venture will be based in Xi’an, with \$32 million in registered capital and more than \$100 million in initial development funds (Honeywell will invest \$40 million). The company intends to supply the export market until the C919 enters production, after which it expects 60 percent of contracts to be domestic (“Honeywell to Supply Flight Control System for the C919 Large Airliner,” 2010).

According to company statements, Honeywell’s Aerospace division is actively developing local sourcing and engineering projects with leading Chinese aerospace manufacturers and universities. Honeywell has collaborated for many years with the Shanghai-based China Aeronautical Radio Electronics Research Institute (CARERI) on air traffic

control responder systems, traffic collision avoidance systems (TCAS), etc. (Liu, 2009, p. 61). Honeywell also maintains a number of wholly owned research facilities in China. These include the Honeywell Technology Solutions Lab–China (HTSL-China), which provides “world-class software product development support, research and technology development, technical consulting and digitization services to Honeywell businesses worldwide” (“Honeywell Technology Solutions Lab”). The largest department in HTSL-China is the Aerospace Electronic Systems department, which employs 55 engineers, 30 percent of whom have more than 5 months’ training or work experience in the United States. In addition to developing products for Honeywell, the lab also “helps local customers in China on avionics products/system development/support by using Honeywell technologies” (“Honeywell Technology Solutions Lab”). Other Honeywell divisions such as Specialty Materials, Transportation, and Automation & Control also maintain specialized research facilities in China.

In November 2009, Honeywell opened its China Aerospace Academy in Shanghai to train aerospace engineers. The courses offered include Technology, Certification, Program Management, Six Sigma Management & Leadership Training, Air-Worthiness Training, and Total Quality Management (“Honeywell China Aerospace Academy Opens; Provides Training to Customers,” 2009).

Parker Aerospace

Parker Aerospace has the following joint venture in China:

- Unspecified interest in a prospective joint venture with the AVIC Systems Company to be based in Nanjing, announced in April 2010. The new venture will support the development of the hydraulic and fuel systems for the C919. A significant portion of the systems’ component design, testing, manufacture, and integration will take place at the new facility. The program is expected to generate more than \$2.5 billion in revenue over its life cycle for Parker (“Parker Aerospace, COMAC, and AVIC Systems Hold Contract Signing Ceremony for Fuel, Inerting, and Hydraulic Systems on New C919 Aircraft”).

Pratt & Whitney

Pratt & Whitney has the following joint ventures in China:

- 78.3-percent interest in Chengdu Aerotech Manufacturing Co., Ltd., a joint venture with a Chinese consortium led by the Chengdu Engine Group Company. With an initial investment of \$25.1 million, it was the first Sino-foreign joint venture in the aviation industry when it was established in February 1996. The company produces components for commercial aircraft engines and industrial gas turbines. Currently it employs more than 200 employees (“Chengdu Aerotech Manufacturing Co., Ltd.”).
- 20-percent interest in Xi’an Airfoil Technology Co., Ltd., a three-partner joint venture with the Xi’an Aero-Engine Group (51 percent) and Israeli-based Pratt & Whitney joint venture Blades Technology International (29 percent), established in 1997. The company produces compressor airfoils. With a production capacity of \$60 million in annual sales, the company produces mainly for export (“Xi’an Airfoil Technology Co., Ltd.”).
- Pratt & Whitney (Canada) holds a 49-percent interest in Zhuzhou South Pratt & Whitney Aero-engine Co., Ltd., a joint venture with China National South Aero-Engine Co. in Zhuzhou, Hunan. The joint venture was launched in 1998 and manufactures components for turboprop aircraft engines. As of 2007, the company had 217 employees (“Zhuzhou South Pratt & Whitney Aero-engine Co., Ltd.,” 2007).
- 49-percent interest in the Shanghai Pratt & Whitney Aircraft Engine Maintenance Company, a CFM56 engine overhaul facility, with Shanghai-based China Eastern Airlines. Established in 2006 with an initial investment of \$99 million, it is said to be the largest (and Pratt & Whitney’s only) engine MRO facility in the Asia-Pacific region (“China Eastern and P&W Partner—Largest Aircraft Engine MRO Facility in Asia-Pacific Goes into Service,” 2009).

Rockwell Collins

Rockwell Collins has the following joint ventures in China:

- Unspecified interest in a prospective joint venture with China Electronics Technology Avionics Co., Ltd (CETCA), announced in July 2010, to provide communications and navigation equipment for the COMAC C919 project. The prospective venture is expected to be based in Chengdu, Sichuan ("Rockwell Collins Selected to Provide Communication and Navigation Systems for COMAC C919," 2010).
- Unspecified interest in a prospective joint venture with China Leihua Electronic Technology Research Institute (LETRI), announced in July 2010, to provide an integrated flight-data surveillance system for the COMAC C919 project. LETRI, a research division of AVIC, has previously worked with Rockwell Collins to assemble and test weather radar, radar antenna mounts, and TCAS equipment for inclusion in Rockwell Collins' surveillance systems sold to airlines throughout the world. The prospective new venture is expected to be based in Wuxi, Jiangsu ("Rockwell Collins to Provide Integrated Surveillance System for COMAC C919," 2010).

In connection with its successful bid to supply the C919's cabin core system, Rockwell Collins will collaborate with the Shanghai Aero Measurement-Controlling Research Institute (SAMRI) in the design, development, and integration of the system. According to Rockwell statements, the new system will leverage innovations from the Rockwell Collins Venue Cabin Management System to develop a "next-generation backbone" for the C919's cabin core system. SAMRI is a subsidiary of AVIC ("Rockwell Collins Selected to Provide Cabin Core System for COMAC C919," 2010).

Sikorsky Aircraft Corporation

Sikorsky's industrial cooperation with China dates back to 1995, when a Chinese consortium led by the Changhe Aircraft Industries Corporation and the China Helicopter Research and Development Institute participated in Sikorsky's Team S-92 project and undertook the design and manufacture of the S-92's tail pylon and horizontal stabilizer. China's role in the project is limited, and the project has not led to

significant Sikorsky sales in China. As of 2008, China had purchased only one S-92A in the offshore oil support role, and between 1998 and 2008, Sikorsky sold only 17 medium helicopters and 24 light helicopters in China (Zhang, 2008, p. 38; Zhao and Ma, 2009, p. 63). Nevertheless, it is claimed that the project helped the Chinese helicopter industry take a major step forward in modern manufacturing and industrial management techniques. After a decade of relatively slow development, Sikorsky's Chinese presence received a major boost in June 2006, when Sikorsky signed an MOU with AVIC II for collaboration on the development and production of civil helicopters. Several subcontracts and joint ventures soon followed.

In 2003, Sikorsky established a joint-venture subsidiary in Shanghai with a Chinese private-sector developer of light and ultralight helicopters. Initially, the company was engaged primarily in providing maintenance services and training classes to Sikorsky's Chinese customers. In January 2008, the joint venture was reorganized, with AVIC joining as the lead Chinese partner through its subsidiaries Changhe Aircraft and Shanghai Xinsheng. The reorganized company had \$6 million in registered capital, with Sikorsky holding a 49-percent stake. The company expanded its business to provide supply-chain management services, as well as post-sales customer support to both Sikorsky's and Changhe's civil fleet in China ("AVIC II Joins Shanghai Sikorsky," 2008; Chen, 2008).

Non-U.S. Companies

Airbus SAS

Airbus China opened its Beijing office in 1990. It now employs more than 270 people in China, the majority of whom are Chinese nationals, and operates a string of local customer-support offices to provide assistance to airlines. Airbus subsidiaries in China include the Hua-Ou Aviation Training Centre in Beijing; the nearby Hua-Ou Aviation Support Centre; the Airbus (Beijing) Engineering Centre (ABEC), where design work on new Airbus programs is conducted; and, newly established in October 2009, a logistics center in Tianjin to optimize supply-chain management for all of Airbus's production facilities in China ("Airbus in China").

Airbus has the following joint ventures in China:

- 70-percent interest in the Airbus (Beijing) Engineering Centre, a joint venture between Airbus and AVIC. Launched in 2006, ABEC's engineers work on specific design packages for new Airbus programs, including the design and development of the Airbus A350 XWB. (China is allocated 5 percent of the design and manufacturing work on the A350 airframe, per a 2007 MOU.) By 2009, the center employed some 200 Chinese engineers ("Industrial Cooperation and Technology Transfers").
- 51-percent interest in Airbus FALC, Tianjin, a joint venture between Airbus and a Chinese consortium of the Tianjin Free Trade Zone and AVIC. The facility performs final assembly of A320-series aircraft ("Industrial Cooperation and Technology Transfers").
- 20-percent interest in Hafei Airbus Composite Material Manufacturing Center, located in Harbin, a joint venture between Airbus and a Chinese consortium led by HAIG. The manufacturing center is intended to supply composite components for the A350 XWB project, as well as the A320 family. Construction began in June 2009, and the new plant delivered its first work package, a set of A320 elevators, in July 2010. The facility will supply elevators, rudders, and horizontal-tail-plane spars for the A320 and is also an exclusive supplier for A350 rudders, elevators, and maintenance doors. The facility expected to employ 100 workers by the end of 2010 and 600 by 2016 ("Airbus Harbin JV Plant Delivers 1st Work Package," 2010).

In addition, Airbus has provided technical training to thousands of maintenance engineers, pilots, and cabin crew (many of whom were from outside China) at its Beijing training center since 1998. Billed as "the most modern such facility in the country," the training center contains two full simulators, one for the A320 family and one for the A330/A340 family ("Airbus in China").

Airbus has also experimented with other forms of industrial collaboration. For example, following the cancellation of the Airbus-AVIC AE31X program in 1998, Airbus invited Chinese participation in the

design of the A318, a shortened derivative of the A319 developed as a low-cost alternative to the AE31X as Airbus's entry in the regional jets category. Subsequently, a team of Chinese engineers participated in the development of the new aircraft ("Airbus in China").

AgustaWestland

AgustaWestland is a relative latecomer to China, having delivered only about 25 helicopters to Chinese operators as of late 2009. Agusta's industrial collaboration with China began in 1999, when Agusta was awarded a \$30 million contract to design and develop the transmission system for the China Medium Helicopter program ("Agusta and Jiangxi Changhe Aviation Industries Signed a Joint Venture Agreement," 2004).¹ In 2004, Agusta formed a joint venture with Changhe Aircraft for the production and local support of the Agusta A109 helicopter. As of 2009, the joint-venture company, the Changhe Agusta Helicopter Co., Ltd., had the capacity for final assembly of the A109, as well as the ability to manufacture the fuselage and various other components. Agusta is reportedly considering introducing other models for final assembly in China (Zhao and Ma, 2009, p. 66).

Antonov Aeronautical Scientific/Technical Complex

Although Antonov ASTC, of Ukraine, has a long-standing relationship with the Chinese aviation industry, most of that collaboration has been focused on the development of military transports such as the turboprop Y-8. Antonov's participation in the commercial aircraft sector has been more limited, although it provided key assistance in critical areas such as wing design, integral airframe construction strength analysis, and various wind-tunnel tests for the ARJ21 ("Building of the First ARJ-21 Designed with the Participation of Antonov Is Completed," 2007). However, Antonov does not appear to be involved in the C919 project, based on available information. As of November 2010, Antonov does not have any known subcontracting or joint-venture relationships with the Chinese aviation industry.

¹ According to Jane's, the program became the basis for the WZ-10 attack helicopter. See Endres, 2006.

Bombardier

Bombardier's presence in China is concentrated primarily in its rail-transportation division, which employs more than 3,500 people through three joint ventures and seven wholly foreign-owned enterprises. The company's China operations are headquartered in Beijing, and its commercial aircraft and customer-services operations are based in Shanghai. Its business aircraft operations are based in Hong Kong ("Bombardier in China").

During the 2007 Paris Air Show, Bombardier Aerospace signed a risk- and revenue-sharing agreement with AVIC to develop the ARJ21-900, the 105-seat version of AVIC's new regional jet (Butterworth-Hayes, 2010, p. 27). According to company statements, Bombardier will provide technical assistance in the development of the ARJ21 program. In 2008, Bombardier gave long-time subcontractor Shenyang Aircraft Co. design authority on major supplied parts of Bombardier's new C-series regional jets. In addition, through its design information-technology system, Bombardier is linking its offices in Montreal to SAC's Shenyang offices for online, live knowledge-sharing ("Bombardier in China: Local Partners and Suppliers").

Embraer SA

Embraer SA opened its first representative office in Beijing in May 2000. Over the next decade, the company established a spare-parts distribution center in Beijing and opened the first Embraer production facility outside of Brazil, a joint venture with HAIG in Harbin to produce the ERJ 145 family of aircraft. As of 2007, the company employed 230 people in China at its various subsidiary units ("Embraer in China").

Embraer has the following joint venture in China:

- 51-percent interest in Harbin Embraer Aircraft Industry (HEAI), a joint venture between Embraer and HAIG.

The Eurocopter Group

Eurocopter's industrial collaboration with China dates back to 1980, when its predecessor Aérospatiale contracted with HAIG to produce the

4-ton-class AS365N Dauphin II under license as the Z-9. The program proved highly successful, and HAIG became Eurocopter's primary partner in China. At the same time, Eurocopter became a leading source of technology for the Chinese helicopter industry, receiving a \$70 million to \$80 million contract in 1997 to help develop the rotor system for a new Chinese medium helicopter, subsequently associated with the Z-10 attack helicopter (Endres, 2006). Over time, Eurocopter became the leading foreign helicopter maker in China, accounting for more than 40 percent of the Chinese civil helicopter fleet as of 2009. Eurocopter senior management acknowledges that the key to the company's success lies in its willingness to collaborate on the basis of the latest available technology (Zhao and Ma, 2009, p. 65).

To date, Eurocopter's joint projects with HAIG include:

- Licensed production of the AS365N Dauphin II as the Z-9. The initial 1980 agreement provided for 48 sets of AS365N kits to be assembled in Harbin, and in 1993, a follow-on contract for 22 additional sets was signed. In 1992, the Z-9B, an "indigenized" variant with 71.9 percent Chinese-made content, made its first flight. It is believed that the PLA subsequently took delivery of more than 150 Z-9Bs and its follow-on variants. Over time, the Z-9 became the most produced helicopter series in China, with over 200 units delivered to military and civilian customers so far. HAIG has also developed several improved variants of the Z-9, the latest of which is the H450, with an enhanced payload. The PLA is said to be interested in adopting this variant to replace its older Z-9s if the program is successful ("Zhi-9 Utility Helicopter," 2009).
- Joint development and co-production of the EC-120/HC-120 in a three-way partnership between Eurocopter, HAIG, and Singapore Technologies Aerospace, Ltd. (STAero), contracted since 1993. The EC120 is a single-engine light helicopter with a maximum takeoff weight of approximately 1,700 kg. Its design is considered highly advanced, with extensive use of composite materials and a new-generation shrouded tail rotor. At the time of the

project's launch, it was the first Chinese risk-sharing partnership in a helicopter program ("HC-120 Helicopter").

Initially HAIG, which has a 24-percent stake in the program, produced the fuselage and fuel system for the machine, while Eurocopter (61 percent) was responsible for overall technological leadership and final assembly. In 2004, a second assembly line with the capacity to produce 20 aircraft per year was opened in Harbin, although HAIG continues to supply the fuselages on all EC120s produced. To date, more than 600 EC120s have been delivered to customers around the world (Zhao and Ma, 2009, p. 65). One operator is U.S. Customs and Border Protection, which has 15 of these aircraft.

- Joint development of the EC175/Z-15 7-ton-class medium utility helicopter, contracted in 2006. The project is a 50-50 joint venture between Eurocopter and HAIG, with Eurocopter serving as the technical lead and systems integrator. Eurocopter has responsibility for the EC175's main gearbox, tail rotor, avionics, doors, and transparencies, while HAIG is responsible for the airframe, tail and intermediate gearboxes, main rotor, fuel system, flight controls, and landing gears (Zhao and Ma, 2009, p. 65). The first prototype made its first flight in December 2009 (Dubois, 2010).

While all versions of the aircraft were originally expected to be powered by two Pratt & Whitney Canada PT6C-67E turboshafts, in early 2010, French engine-maker Turbomeca confirmed that it will collaborate with AVIC to develop a new turboshaft based on the Turbomeca Ardiden engine for the Chinese Z-15. AVIC will develop the compressor and the engine installation in Harbin, and Turbomeca will develop the hot section and controls. The new engine, identified as the WZ60, is said to offer 15 percent better fuel economy. But perhaps even more important for the Chinese, a Chinese engine would avoid potential U.S. embargoes on the Pratt & Whitney engine once the Z-15 enters Chinese military service (Morris, 2010).

In addition, since 2002, Eurocopter has been a partner (having a 34-percent interest) in the CITIC Offshore Helicopter Company (COHC) General Aviation Maintenance and Engineering Co., a Shenzhen-based MRO joint venture with COHC. The facility is said to be the largest helicopter MRO facility in China and the only such facility in China to receive European Aviation Safety Agency (EASA) certification (Zhao and Ma, 2009, p. 65).

Liebherr Aerospace, SAS

Liebherr has the following joint ventures in China:

- 50-percent interest in Liebherr Hangda Aerospace Technologies (Wuhan) Co., Ltd., a joint venture with the Wuhan Hangda Aero Science and Technology Development Co. The facility opened in 2007 and provides maintenance service on all Liebherr Aerospace products, including heat exchangers installed on Airbus, Boeing, Bombardier, and Embraer aircraft, as well as future COMAC aircraft operating in China (“Liebherr-Aerospace Establishes Joint Venture with a Chinese Partner,” 2007).
- Unspecified interest in a prospective joint venture with AVIC subsidiary Landing-gear Advanced Manufacturing Co., Ltd. (LAMC) in Changsha, Hunan, announced in July 2010. The joint venture will supply the landing-gear system for the COMAC C919, including the main landing gear and nose landing gear, extension and retraction system, nose-wheel steering system, and position and warning system (“Liebherr-Aerospace Selected for the New Chinese Aircraft Program C919,” 2010).
- A technology-cooperation and work-share agreement with AVIC subsidiary Nanjing Engineering Institute of Aircraft Systems (NEIAS), announced in July 2010, to supply the air management system of the COMAC C919. The package will include the bleed air system, the air-conditioning system, the air-distribution system, the cabin-pressure control system, the wing anti-ice system, and the avionics ventilation system. Liebherr hopes that the work-share partnership established with NEIAS can be used

for future projects (“Liebherr-Aerospace Selected for the New Chinese Aircraft Program C919,” 2010).

Rolls-Royce Group PLC

Rolls-Royce has the following joint ventures in China:

- Unspecified interest in XR Aero-components, Ltd. (XRA) in Xi'an, a joint venture with the Xi'an Aero Engine Company, established in 1996. Rolls-Royce describes XRA as a “high-tech joint venture” specializing in the manufacture of turbine-nozzle guide vanes and low-pressure turbine blades for use in Rolls-Royce engines on various Gulfstream, Bombardier, and Boeing aircraft. The facility has been in operation since 1998 (“Working Together,” 2009).
- Unspecified interest in Hong Kong Aero Engine Services Limited (HAESL) in Hong Kong (“Rolls-Royce in Hong Kong,” 2009).

Rolls-Royce's technological partnership with the Chinese aviation industry dates back to the 1970s, when the company first transferred overhaul technology for its Spey 512 engine (used on Hawker Siddeley Trident civilian jetliners) to China and then, in 1975, granted a production license for the military-use Spey 202 to the Xi'an Aero-Engine Company, along with 50 complete engines. It took decades for China to master the production technology for the Spey, however, and in 2001, another 80 to 90 reconditioned British-made Speys were delivered to China. Actual production of the Spey 202 (designated the WS9 Qin Ling in China) in Xi'an apparently did not begin until about 1998. As of 2008, at least 110 XAC JH-7 fighter-bombers, the only aircraft in China that uses the Spey, were estimated to have been produced. Since each JH-7 is equipped with two engines, this would mean that at least 80 Speys had been produced in China at that point, suggesting that the production technology has now been mastered (“Rolls-Royce China”; “History,” 2009; “Rolls-Royce Spey,” 2010; “XAE WS9 Qin Ling,” 2010; “XAE—Xian Aero-Engine Corporation,” 2010).

Since the 1970s, Rolls-Royce has deepened its relationship with China. It has developed technical and managerial training programs

with a range of Chinese organizations, including AVIC, CAAC, and several government ministries. In particular, Rolls-Royce collaborates with CAAC in operating a joint facility in Tianjin, established in 1997, for the training of technicians, engineers, and managers (“Rolls-Royce China”; “History,” 2009).

In addition, Rolls-Royce is involved in a number of research programs with Chinese universities and research institutes in the area of aerospace engine technology. These include the Joint Engineering Team (JET) program with AVIC and a more recent (February 2009) joint research project with the Chinese Academy of Sciences (CAS) focusing on new manufacturing techniques and materials for low-pressure turbine blades. In July 2010, Rolls-Royce signed an MOU with HAIG regarding collaboration in composite-materials research (“Rolls-Royce: Procurement in China to Increase Three- to Four-fold over the Next Five-to-Eight Years,” 2010).

The Safran Group

Safran Turbomeca and AVIC II started working together in the 1980s, when Turbomeca granted the China National South Aero Engine Corporation (SAEC) a production license for the Arriel 1 engine for the Z-9 helicopter. Today, Turbomeca is the leading helicopter engine-maker in China, with 500 engines serving in both the civilian and military sectors, equipping roughly half of the Chinese helicopter fleet (“Turbomeca [Safran Group] Signs Agreement for Training Programs in China,” 2009). In 2005, Turbomeca secured a major contract for 200 Arriel 2C turboshaft engines from AVIC II, along with a partial production license. In connection with the contract, a cooperation framework agreement was signed, providing for increased collaboration with the Chinese aerospace engine industry. Turbomeca’s first manufacturing joint venture in China was the Beijing Turbomeca Changkong Aero-Engine Control Equipment Co., Ltd., a partnership with AVIC subsidiary Beijing Changkong Machinery, established in 2006. The facility assembles and tests fuel-control units and hydro-mechanical units of turboshaft engines for both Turbomeca and Beijing Changkong (“Signature Between Turbomeca and Beijing Changkong Machinery for a Joint Venture Company,” 2006). In late

2009, Turbomeca formed another partnership with the Civil Aviation Flight University of China (CAFUC). The new venture will develop a Turbomeca maintenance training program in Chengdu to qualify advanced line-maintenance engineers (“Turbomeca [Safran Group] Signs Agreement for Training Programs in China,” 2009). In early 2009, Turbomeca revealed that it was participating in a 50-50 joint venture with AVIC to develop a new-generation 1,500-kW turboshaft engine, to be manufactured primarily in China. The project was said to be the first joint development of an aerospace engine between China and a Western aerospace company (Zhang and Liu, 2009, p. 50). Subsequently, Turbomeca confirmed that it was co-developing a derivative of its Ardiden engine with China to power the Z-15/EC-175 medium helicopter. The Z-15 is expected to be dual-use, and the new engine would allow the Chinese to avoid potential U.S. embargoes on its original Pratt & Whitney engine. Turbomeca engines have already been licensed by the French government for military export (Morris, 2010).

The Safran Group also has the following joint ventures in China:

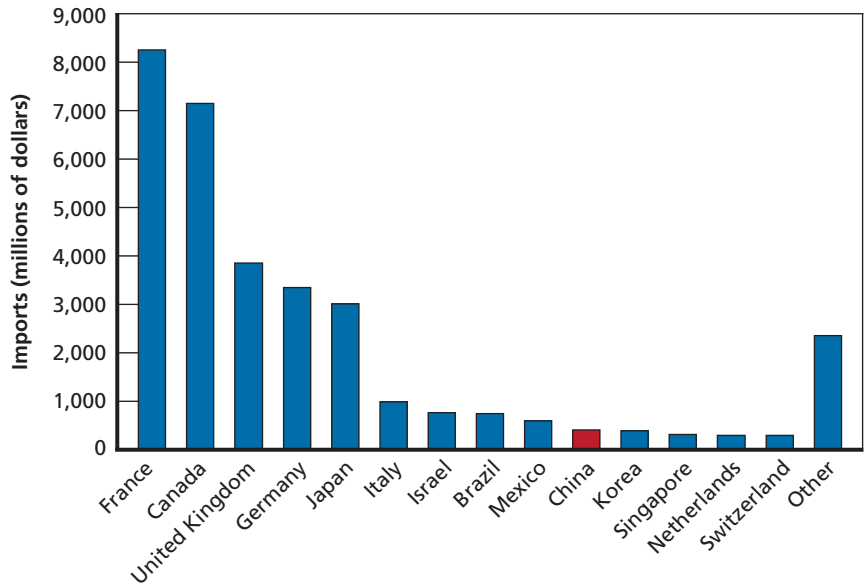
- 51.8-percent interest in the Sichuan Services Aero Engine Maintenance Co., a Chengdu-based joint venture with the Air China Group, established in 1999. The facility offers a wide range of MRO services for CFM56-3, CFM56-5B, and CFM56-7 engines (“Worldwide—Sichuan Services Aero Engine Maintenance Company [SSAMC]”).
- 85-percent interest in the Snecma Xinyi Airfoil Castings Co., Ltd., a Guiyang-based joint venture with the Guizhou Xinyi Machinery Factory, established in July 2006. The plant produces low-pressure turbine blades, nozzle guide vanes, and low-pressure turbine seals for the CFM56 family of commercial jet engines (“Worldwide—Snecma Xinyi Airfoil Castings”).

Extent to Which China-Based Production Supplies U.S. Aerospace Firms

The value of aerospace imports to the United States from China was about \$421 million in 2009, about 1 percent of total U.S. aerospace imports. This made China the tenth most important aerospace supplier to the United States. See Figures 4.1 and 4.2. By contrast, aerospace exports to China from the United States totaled \$5.314 billion in 2009, or 6.5 percent of U.S. aerospace exports. See Figure 4.3. The disparity between these figures should not be taken to imply that the United States is contributing more to China's aviation industry than China is contributing to the U.S. aviation industry. The vast majority of aerospace exports from the United States to China appear to be complete aircraft sold directly to Chinese airlines. In 2009, Boeing sold 72 large commercial airplanes to Chinese airlines, including 61 737s, four 747s, and seven 777s ("Orders and Deliveries"). Boeing does not disclose the total amount paid for these aircraft, but according to Boeing's website, 737s cost between \$60 million and \$80 million, while both the 747 and 777 cost more than \$200 million each ("Commercial Airplanes—Jet Prices"). If the Chinese airlines paid \$60 million for each 737 and \$200 million for each 747 or 777, the total amount would have been \$5.86 billion, more than actual U.S. aerospace exports to China that year. Even if the Chinese airlines paid only 90 percent of these amounts, these sales would account for all but \$40 million of U.S. aerospace exports to China in 2009. Most of the exports from China to the United States, by contrast, are inputs to final products that are completed in the United States.

Aerospace imports from China grew at an average annual rate of 25 percent between 2005 and 2009, while total aerospace imports from all sources grew at an average annual rate of only about 6 percent, suggesting that China's share of U.S. aerospace imports will likely increase rapidly in coming years.

Figure 4.1
U.S. Aerospace Imports, 2009



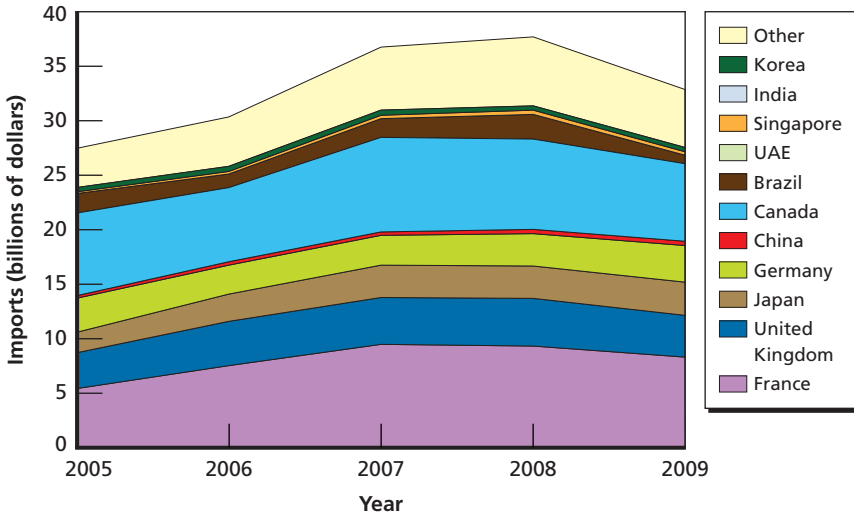
SOURCE: International Trade Administration, Department of Commerce, 2010.

RAND MG1100-4.1

Most China-based production that supplies U.S. (and other Western) aerospace firms comes from either the joint ventures described above or the various subsidiaries of AVIC. According to figures released at AVIC's 2009 company summit meeting, the total value of the company's subcontract deliveries in 2008 reached \$639 million, a 35-percent year-on-year increase over 2007. More than half of that value came from engine subcontracts, which accounted for \$330 million ("AVIC Aims to Deepen Reform in 2009," 2009).

To date, Boeing is by far the largest foreign customer of the Chinese aviation manufacturing industry. According to information released by Boeing, since the 1980s, Boeing has purchased more than \$1.5 billion of aviation hardware and services from China, and it holds active contracts with Chinese suppliers valued at more than \$2.5 billion. All of Boeing's commercial aircraft lines now incorporate parts

Figure 4.2
U.S. Aerospace Imports, 2005–2009

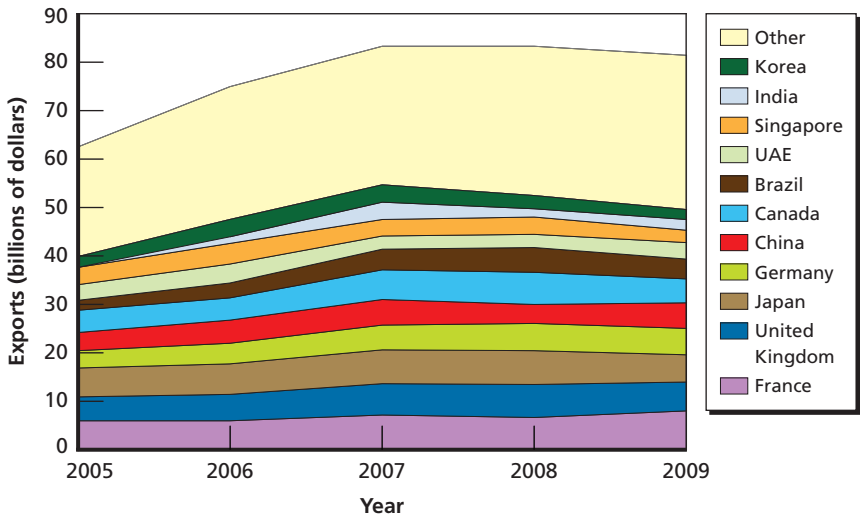


SOURCE: International Trade Administration, Department of Commerce, 2010.

RAND MG1100-4.2

and assemblies built in China, although most of these parts are relatively minor. Boeing's subcontract relationship with China received a major boost in 2005, after China contracted with Boeing for up to 60 Boeing 787 Dreamliners, a deal worth \$7.2 billion at list prices. Soon after, a number of Chinese firms were selected as exclusive, single-source suppliers for the 787, and Boeing also "introduced" its existing network of suppliers to Chinese firms, encouraging them to purchase from Chinese suppliers. To date, U.S.-based Boeing suppliers with Chinese subcontracting relationships include the Eaton Corp. (777 fuel-system components), GE (jet engine components and parts assembly), Goodrich (jet engine fan cowls, 787 nacelle components), Honeywell (cabin management systems, engine parts, and other avionics components for the 737 and 757), and Pratt & Whitney (engine components, such as compressor airfoils).

Figure 4.3
U.S. Aerospace Exports, 2005–2009



SOURCE: International Trade Administration, Department of Commerce, 2010.

RAND MG1100-4.3

It is worth noting that many of these subcontracts are themselves correlated with the U.S. supplier's success in penetrating the Chinese market. For example, while GE's purchase of jet engine components in China reached \$284 million in 2007, Chinese engine orders with GE reached more than \$1 billion (list price) that year. In addition, some of the Chinese production subcontracts increase American exports in other sectors, and joint ventures with Chinese firms may create jobs in the United States. The aluminum alloys used for Xi'an Aircraft's subcontract for 737 vertical-tail assemblies and Shanghai Aircraft's subcontract for horizontal stabilizers, for instance, are sourced mainly from Alcoa's production facilities in Indiana and Arizona. And GE's new joint venture with AVIC Systems to produce avionics systems will reportedly create more than 200 jobs in the United States.

Finally, although Boeing and many of its U.S.-based first-tier suppliers have established MRO service facilities in China, most of the customers who presently use these facilities are Chinese.

The major Western aviation-component production subcontracts and servicing agreements in China that we were able to identify are described below.

U.S. Companies

Alcoa, Inc.

Alcoa operates a wholly owned fastening-systems manufacturing facility in Suzhou (Alcoa Fastening Systems (Suzhou) Co., Ltd.), which began operations in 2006, as well as aerospace service and logistics facilities in Shanghai (“Alcoa in China”).

Alcoa has been a long-term supplier of aluminum products to Chinese aircraft manufacturers for their Boeing subcontracts. These manufacturers include the XAC for Boeing 737 vertical-tail assemblies and the Shanghai Aircraft Manufacturing Factory for Boeing 737 horizontal-stabilizer assemblies. However, none of these contracts was sourced from Alcoa’s China facilities. Instead, the aluminum was produced at facilities in Indiana, Arizona, and South Korea (“Alcoa Expands Supplier Relationship with Shanghai Aircraft of China,” 2005). Similarly, although Alcoa materials are used extensively on the COMAC ARJ21, all of them are sourced from facilities outside of China. These materials include advanced heat-treated sheet and plate alloys used throughout the aircraft from Alcoa’s Davenport, Iowa, plant; extrusions made from proprietary alloys and process technologies for the wing and fuselage stringers and floor beams, sourced from Alcoa’s Lafayette, Indiana, Chandler, Arizona, and Changwon (South Korea) plants; and airfoil castings and structural components from Alcoa’s power and propulsion plants in Whitehall, Michigan, and Wichita Falls, Texas (“Alcoa Advanced Aerospace Alloys and Materials Used on China’s First Home-Produced Regional Jet, ARJ21-700,” 2008).

The Boeing Company

According to information released by Boeing, since the 1980s, Boeing has purchased more than \$1.5 billion of aviation hardware and services from China. Today, Boeing and Boeing suppliers have active supplier contracts with China’s aviation industry valued at over \$2.5 billion, and Boeing claims to be the largest foreign customer of the Chinese

aviation manufacturing industry. All of Boeing's commercial aircraft lines now incorporate parts and assemblies built in China. However, Boeing does not release annual procurement numbers ("Boeing in China," 2007).

Current Boeing work packages and procurement at Chinese enterprises include major parts (including some composite parts) on the 787 Dreamliner, the 747-8, and in particular, the 737NG. China is also the first location for the 747-400 Boeing Converted Freighter (BCF) program, which converts older 747 passenger aircraft into freighters ("Boeing in China," 2007). Boeing's subcontracting relationships in China are summarized in Table 4.3.

In 2005, Boeing selected a number of Chinese manufacturers to be suppliers to the 787 program. These contracts marked several milestones in Boeing's relationship with China: For the first time, Chinese firms were selected as exclusive, single-source suppliers for a major new airliner, and also for the first time, essential composite structures were subcontracted to Chinese suppliers. According to Boeing, the value of the 787 packages in China could reach several hundred million dollars over the lifetime of the program. In addition, Boeing for the first time "introduced" its global network of suppliers to Chinese firms, "encouraging them to engage with Chinese industry." As a result, China has gained a "very significant, expanding role in the Boeing supplier network at all levels" ("Boeing's Investments in China," 2010).

Cytec Engineered Materials

Cytec Engineered Materials operates an aerospace composite-materials production facility in Shanghai to supply carbon fiber epoxy prepreg material for commercial transport programs throughout the Asia-Pacific region ("Cytec Eyes Jumbo Jet Options," 2009).

Eaton Corporation

Eaton began its operations in China in 1993 with a joint venture in Shandong to manufacture steering-control units and hydraulic motors, a venture that it subsequently acquired. Today, Eaton operates roughly 30 production facilities in China, the majority of which are wholly

Table 4.3
Current Boeing Work Packages and Procurement at Chinese-Owned Enterprises

Subcontractor	Product Group					
	737 Series	747 Series	767 Series	777 Series	787 Series	Misc.
Baoji Group Ltd., Shaanxi (since 2006)						Titanium ingot, plate, and sheet
Boeing Tianjin Composites Co., Tianjin (Boeing joint venture since 2002)	Composite panels and parts, including flight deck, closeout panels, dorsal fin, wing-to-body fairing, cover panels, wing fixed trailing edge, wing fixed leading edge, tail cone, interior panels	Misc. composite panels, door liners, fixed trailing edge	Wing fixed trailing edges, dry bay barriers, empennage panels	Wing fixed trailing edges, dry bay barriers, flight-deck interior panels, empennage panels	Trailing edge panels for the vertical fin (2005), additional panels (2007), wing- to-body fairing supplier assistance	
Changhe Aircraft Industries Co., Jingdezhen, Jiangxi (since 2008)			Components for 767-300 freighter conversion			
Chengdu Commercial Aircraft, Sichuan (since 2005)	Forward entry doors, overwing exit doors	747-8 ailerons and spoilers, single source (contracted 2007, first delivery 2009); 747-8 horizontal stabilizer parts and subassemblies (contracted 2007)			Composite rudder, single source (contracted 2005, first parts delivery 2006, first full rudder 2007)	

Table 4.3—Continued

Subcontractor	Product Group					
	737 Series	747 Series	767 Series	777 Series	787 Series	Misc.
HAIG, Harbin (since 2005)					Upper and lower panels for wing-to-body fairings, single source (contracted 2005, first delivery 2007); vertical fin parts (contracted 2007); tier-III detailed parts (first delivery 2008)	
Hong Yuan (HYFC), Sanyuan (since 1984)		Titanium forgings, 12 for each 747				
Shanghai Aviation Manufacturing Company (since 1995)	737NG horizontal stabilizers (contract 1995; more than 1,200 sets delivered)					
Shaanxi Aircraft Industry Co., Hanzhong, Shaanxi (since 2008)			Components for 767-300 freighter conversion			
Shenyang Commercial Aircraft Company, Liaoning (since 1996)	Aft fuselage subassemblies (1996/2001), expanded to include "Texas Star" (2004), expanded to full aft section 48 (2007)				Vertical-fin leading edge, single source (contracted in 2005, first delivery 2007)	

Table 4.3—Continued

Subcontractor	Product Group					
	737 Series	747 Series	767 Series	777 Series	787 Series	Misc.
Southwest Aluminum, Chongqing (since 1988)		Aluminum forgings, four for each 747				
Quick Electronics, Beijing (since 1997)						PC, print hardware, servers in support of Boeing IT Asia
Taikoo Aircraft Engineering Co., Xiamen (Boeing joint venture since 2004)		Parts, subassemblies, and touch labor for 747-400 BCF program				
Xi'an Aircraft Industrial Co. (since 1995)	737NG vertical fin (contracted 1995; 1,000 delivered)	747-400 fixed trailing edge wing ribs, single source (contract 1996, more than 550 sets delivered), 747-8 inboard flaps, single source (contract 2007, first delivery 2009), 747-8 fixed trailing edge wing ribs (contracted 2007, initial delivery 2008), 747 floor beams and subassemblies for BCF program (2004)				

owned, with about 10,000 employees and total sales approaching \$1 billion in 2010. Eaton's facilities in China make products for all of Eaton's distinct businesses, from aerospace to automotive ("Eaton in China Fact Sheet"). Eaton is a components supplier to the Chinese aviation industry and supports other foreign first-tier suppliers on programs including the ARJ21, the MA60, and the Embraer ERJ145. In 2010, Eaton announced a joint venture with AVIC to supply the fuel and hydraulic systems for the COMAC C919.

Eaton has also developed extensive local sourcing relationships with Chinese suppliers. Most recently, Eaton signed a six-year supply agreement with AVIC subsidiary Shenyang Liming Aero-Engine Group to supply fuel-system components to be used on the Boeing 777 as well as all Airbus aircraft (Liu, 2009, p. 64).

General Electric (including CFM International, Nexcelle)

General Electric has an extensive presence in China, with more than 50 manufacturing and service facilities in the country employing some 13,000 employees. In 2009, GE's total annual revenues in China exceeded \$5.3 billion ("GE in China").

Over the past decade, GE Aviation has emerged as the leading jet engine supplier in China. As of 2008, there were about 2,000 GE and CFM engines in service, with an additional 1,000 on order valued at more than \$5 billion (list price) ("GE Jet Engine Backlog Climbs to \$5 Billion in China," 2008). As of September 2010, GE Aviation operated five facilities in China, including the CFM International Spares Service Center in Beijing (established in 1996), an on-wing support facility in Xiamen (established in 1998), an engine-overhaul joint venture also in Xiamen (established in 1999), the China Operations Center in Shanghai (established in 2006) to provide customer support, and a new 200,000-sq-ft systems manufacturing facility in Suzhou (established in 2009) to produce autoclaved composite parts, mechanical fabrications, structure assembly, and civil-aircraft actuation systems ("GE Expands with New Facility Opening in Suzhou," 2009).

GE Aviation maintains subcontracting relationships with Chinese manufacturers dating back to 1986. As of September 2010, its most important local supplier was the Xi'an Aero Engine Corp. (contracted

since 1996), designated a manufacturing technology center to supply components for the CFM56-series jet engines (“CFM56 Sourcing and Spare Parts Programs Launched in China”). In September 2007, GE also contracted with AVIC subsidiary Shenyang Liming Aero Engine Group to supply components and undertake parts assembly and testing for the CF34-10A engines on the COMAC ARJ21 (“GE: We Believe in the Potential of the Chinese Market,” 2008, p. 17). In addition, GE procures various other aviation components from Chinese firms in Harbin, Shanghai, Sichuan, and Guizhou. In 2007, GE’s purchases of jet engine components in China reached \$284 million, while Chinese engine orders that year were valued at more than \$1 billion (list price) (“GE Jet Engine Backlog Climbs to \$5 Billion in China,” 2008). In 2008, GE Aviation’s direct sourcing in China totaled \$365 million (“GE Aviation’s Presence in China Continues to Grow,” 2008).

In fall 2009, GE Aviation concluded a number of MOUs with AVIC, establishing three joint ventures in connection with GE’s bid on the COMAC C919 program. These included a venture to supply engine nacelles and components (“AVIC Aircraft and Nexcelle Announce Plans for a Nacelle Joint Venture in China,” 2009), a venture to supply integrated avionics systems (“GE and AVIC Joint Venture Creates New Global Business Opportunities,” 2009), and a final assembly line for the CFM LEAP-X1C engines (“CFM and ACAE Sign MOU for LEAP-X1C Assembly Line In China,” 2009). GE was subsequently awarded the contracts for the propulsion system, engine nacelles, and avionics-core processing system of the C919 (“CFM Picked to Power China’s Future Plane,” 2010).

Goodrich Corporation

Goodrich launched its first facility in China in 1996, a joint-venture MRO facility with Xiamen TAECO to service engine and flight-control systems, actuation systems, and various other aviation systems and equipment. In June 2009, the company opened another facility in Tianjin to provide nacelle and thrust-reverser MRO services and to support engine buildup and podding work for the new Airbus A320 assembly line in the same city. Later that year, Goodrich signed an

agreement with XAIC to form two joint ventures to produce landing-gear and engine-nacelle components ("2009 Press Releases").

Since 2003, Goodrich has procured CF34 fan cowls from the Boeing Tianjin Composites Co. In 2008, it contracted with Hongdu Aviation in Nanchang to build parts kits for the 787 nacelle (Butterworth-Hayes, 2010, p. 27).

Hamilton Sundstrand

Hamilton Sundstrand launched its first production facility in China in 1994, establishing a joint venture in Shenzhen to produce rotary-screw air compressors. In 2000, it established an additional joint venture in Xiamen to provide MRO services to Chinese airlines. The Hamilton-Sundstrand Industrial (Shanghai) Co., a wholly owned subsidiary, manufactures a range of Milton Roy metering pumps and employs more than 130 workers. Most recently, Hamilton Sundstrand announced a new joint venture with AVIC Systems Co. in April 2010 to supply the electrical system for the COMAC C919 program ("China Locations").

Honeywell International

Honeywell International has an extensive presence in China, with about \$600 million in total investments and more than 9,000 employees spread across more than 30 subsidiaries and local joint-venture companies. Honeywell's Aerospace division supplies key components to several major Chinese aviation programs, including the APU systems for the MA60, the propulsion system for the Z-11, integrated avionics for the Y-12, and various components for the ARJ21 (Liu, 2009, p. 61).

Honeywell Aerospace operates three joint-venture companies and one wholly owned subsidiary in China. These include a joint-venture MRO facility in Shanghai to service wheels and brakes, a joint-venture facility in Xiamen to service APUs and other avionics equipment, a joint venture in Shanghai to produce environmental-control systems, and a wholly owned subsidiary (the Honeywell Aerospace Engine (Suzhou) Co.) to produce cabin-management systems and engine parts mainly for re-export back to the United

States. In November 2008, Honeywell selected HAIG as subcontractor for the HTF7000 engine nacelles used on Embraer business jets (“Honeywell China—Aerospace”). More recently, in July 2010, Honeywell reached an agreement with AVIC subsidiary FACRI to form a 50-50 joint venture to supply the flight-control system for the COMAC C919 (“Honeywell Selected to Provide Flight Control Fly-by-Wire System for COMAC’s C919 Airliner”).

Parker Hannifan

Parker Hannifan was one of the first foreign companies to establish a joint venture in China in the early 1980s. The company currently maintains several regional offices and 11 manufacturing facilities (including at least five joint ventures) in China, employing more than 3,000 employees (“Parker China,” 2009). In April 2010, Parker announced a joint venture with AVIC Systems to supply the fuel and hydraulic systems for the COMAC C919 (“Parker Aerospace, COMAC, and AVIC Systems Hold Contract Signing Ceremony for Fuel, Inerting, and Hydraulic Systems on New C919 Aircraft”). Parker also procures machined components from the Jincheng Corp., the Shanghai Qi Yi Automotive Company, and Sichuan Golden Dragon Machines (Butterworth-Hayes, 2010, p. 27).

Pratt & Whitney

As noted earlier, Pratt & Whitney operates joint-venture production facilities in Chengdu, Xi’an, and Zhuzhou that supply various components for its commercial aircraft engines and industrial gas turbines.

Primus International

Primus International operates a production facility in Suzhou for aircraft components (Butterworth-Hayes, 2010, p. 27).

Rockwell Collins

Although Rockwell Collins has supplied the Chinese market for more than 25 years and has provided a range of avionics equipment for Chinese aircraft, including the ARJ21, MA60, Y-8, Y-12, and K-8 military

trainer, the company did not own any production facilities in China as of September 2010. In connection with its bids on the COMAC C919 project, however, Rockwell Collins concluded two joint-venture agreements with Chinese companies in 2010 to supply the C919's communication and navigation systems and integrated flight-data surveillance system ("Rockwell Collins to Provide Integrated Surveillance System for COMAC C919," 2010). These new ventures will be based in China. In addition, Rockwell Collins won the bid for the C919's cabin-core system and will collaborate with SAMRI in this effort ("Rockwell Collins Selected to Provide Cabin Core System for COMAC C919," 2010).

Sikorsky Aircraft Corporation

As of October 2010, Sikorsky had awarded subcontracts on its three largest commercial helicopter programs to the Changhe Aircraft Industries Corp. in Jingdezhen, Jiangxi. These include:

- Tail-rotor pylon and horizontal stabilizer on the S-92, contracted since 1995.
- Airframe components and assemblies for the Schweizer 300C/CBi light helicopter, contracted since October 2006 ("Schweizer Selects Jiangxi Changhe Aircraft to Provide 300CBi Helicopter Airframes," 2006).
- Airframe components for the S-76C++ medium helicopters, contracted since July 2007 ("Sikorsky Aircraft Selects Changhe to Supply S-76® Helicopter Airframes," 2007).

Smiths Aerospace (GE Aviation subsidiary)

Smiths Aerospace operates a production facility in Suzhou to supply engine parts and flight-control components ("Smiths Opens Aerospace Components Facility in Suzhou," 2004).

Spirit Aerospace

Spirit Aerospace procures Section 48 for Boeing 737s from Shenyang Aircraft Industrial Co.

The Timken Company

The Timken Company operates an aerospace precision-products manufacturing center in Chengdu, established in 2006. The facility employs 200 workers and manufactures ball and cylindrical roller bearings up to 12 inches in diameter (“Timken to Launch Aerospace Manufacturing in China,” 2006). The company also designed a custom bearing solution for AVIC’s MA-60 turboprop liner. Timken has nearly 4,000 employees in China, spread across various large-scale manufacturing facilities serving primarily the automotive and power-generation industries (“MA-60 Aircraft Land on Custom Timken Bearings,” 2008).

Vought

Vought procures 737 overwing exits and forward entry doors and 747-8 horizontal-stabilizer parts and subassemblies from Chengdu Commercial Aircraft Co.

Non-U.S. Companies

Airbus SAS

Airbus’s subcontracting relationship with China began in 1985, soon after Airbus concluded its first sale in China—a contract for five Airbus A310s with the predecessor of today’s China Eastern Airlines. Airbus’s first Chinese subcontractor was XAC, which supplied electronic bay doors for the A300/310 family of aircraft (“Industrial Cooperation and Technology Transfers”; “Airbus in China”).

Airbus’s presence in China has expanded rapidly in recent years. Following a December 2005 Chinese order for 150 A320 aircraft, Airbus procurement in China has increased by an average of some 42.5 percent per year; the company’s annual procurement from China is expected to reach \$200 million in 2010, nearly six times the 2005 level. (For unknown reasons, the English version of the company’s summary of its China presence gives the 2010 procurement figure as \$120 million.) It is said that more than half of the Airbus fleet in service worldwide today contains Chinese components. Airbus also launched three joint ventures with Chinese aviation-industry partners, including a complete final assembly line for the A320 family of aircraft established in Tianjin in 2008 and a composite manufacturing center in Harbin.

According to some reports, annual procurement is projected to reach \$450 million by 2015 ("New Airbus' Logistics Hub in Tianjin to Serve All Projects," 2009).

Airbus's subcontracting relationships in China are summarized in Table 4.4.

Bombardier Aerospace (Canada)

According to Bombardier statements, some components of Bombardier aircraft have been manufactured in China by subcontractors for more than 25 years ("Bombardier in China: Local Partners and Suppliers"). In recent years, Bombardier Aerospace has signed several additional subcontracting agreements with Chinese manufacturers for its Dash-8 Q400 and C-Series aircraft ("Bombardier in China: Local Partners and Suppliers").

Shenyang Aircraft Corp. (SAC) is Bombardier's major subcontractor in China. The contracts include the following:

- Major components, including the empennage and aft and forward fuselage sections on the Dash-8 Q400, amounting to 12 percent of the aircraft by weight, contracted since 2006.
- Fuselage, center wing box, and doors on the C-series regional jet, amounting to more than 10 percent of the work packages, contracted since 2008. According to Bombardier statements, the contract gave SAC design authority on major supplied parts, the first contract of this kind with a Chinese subcontractor in the industry. SAC is to be a risk-sharing partner in the design and manufacture of the contracted parts (Butterworth-Hayes, 2010, p. 27).

Fischer Advanced Composite Components (FACC)

FACC, acquired by XAIC in December 2009, procures interior composite panels from Boeing Tianjin Composites Co. ("Xi'an Aircraft Acquires Austrian Company FACC," 2009).

Table 4.4
Current Airbus Work Packages and Procurement at Chinese-Owned Enterprises

Subcontractor	Product Group				
	A320 Family	A330/340 Family	A350 XWB	A380	Misc.
Airbus Final Assembly Line China, Tianjin (Airbus JV since 2008)	Final assembly of A320 family of aircraft (first delivery 2009)				
Chengdu Commercial Aircraft, Sichuan	Rear passenger door, nose-section components (first delivery 2004)		Spoilers, droop panels (exclusive supplier for both)		
Guizhou Aviation Industry Group					Maintenance jigs and tools
Hafei Airbus Composite Material Manufacturing Center (Airbus joint venture since 2009)	Elevators (first delivery 2010), rudders, horizontal tail-plane spars		Elevators, rudders, maintenance doors, belly fairing components (exclusive supplier for all items)		
HAIG, Harbin	Composite horizontal tail-plane spars, composite horizontal tail-plane torque boxes	Wing-spar joints			
Hong Yuan Aviation Forging and Casting (HYFC), Shaanxi					Titanium forgings
Shanghai Aviation Manufacturing Co.	Cargo door frames (contracted 2006)				
Shenyang Aircraft Industrial Corp.	Emergency exit doors (single source), wing fixed leading edges, wing interspar ribs, skin plates	Cargo doors on freighter aircraft			

Table 4.4—Continued

Subcontractor	Product Group				
	A320 Family	A330/340 Family	A350 XWB	A380	Misc.
Xi'an Aircraft Industrial Co.	Electronic bay doors, wing fixed trailing edges, wing boxes (contracted 2005, first delivery 2007), final wing assemblies (contracted 2009)	Electronic bay doors, brake blades, medium air ducts			

Fokker Aerostructures (The Netherlands)

Since 2005, Fokker Aerostructures has procured components for the Gulfstream G450, G500, and G550 business jets from Shenyang Aircraft Co. (“Shenyang Aircraft Corporation and Fokker Aerospace Group to Work Together in Machining for Gulfstream Aircraft Components,” 2005).

Fokker-Elmo (The Netherlands)

Fokker-Elmo operates a facility in Langfang, Hebei Province, to supply 99 different parts to the Boeing 737 program and 142 to the Boeing 777 program (Butterworth-Hayes, 2010, p. 27).

Korean Aerospace Industries (Korea)

Korean Aerospace Industries procures parts for the vertical fin and the horizontal stabilizers on the 737 from Shanghai Aircraft Industries Corporation, Xi’an Aircraft Company, and Boeing Tianjin Composites Corporation.

Messier-Dowty (Safran subsidiary in France)

Since 2002, Messier-Dowty has had a production facility in Suzhou that supplies medium landing-gear structural components to Boeing (including for the 787), Airbus (in particular, for the A320), Bombardier, Dassault, and Hawker Beechcraft (“Operations—Suzhou”).

Rolls-Royce (U.K.)

Rolls-Royce’s joint-venture production facilities at Xi’an supply turbine-nozzle guide vanes and low-pressure turbine blades for Rolls-Royce engines. Several Chinese-owned enterprises are also important suppliers to Rolls-Royce: Sichuan Chengfa Aero Science and Technology supplies rings, sheet metal, and fabrications; Beijing Aero Lever Precision supplies variable stator vane levers; Shenyang Liming Aero-Engine Group Corp. produces heat-shield rings for the BR700 series engines; and Xi’an Aero Engines Co. supplies other unspecified components. In July 2010, Rolls-Royce reportedly invested RMB4.3 billion to establish a new production plant in Shenyang to supply key components, including stub axles and engine valves for the company’s new Trent

XWB engine (“Rolls-Royce: Procurement in China to Increase Three- to Four-fold over the Next Five-to-Eight Years,” 2010).

According to company executives, Rolls-Royce expects to expand procurement in China three- to four-fold over the next five to eight years, reaching approximately \$1.2 billion annually from a current level of \$250 million (“Rolls-Royce: Procurement in China to Increase Three- to Four-fold over the Next Five-to-Eight Years,” 2010).

Safran-Aviation

The Safran Group's industrial cooperation with China dates back to the early 1980s, when Safran's predecessor, Sagem, transferred autopilot technology to AVIC's Lanzhou plant for the Z-9 helicopter. Small-scale local production of aerospace-engine parts began in 1990 (“Safran History in China”). In 2002, Safran component Messier-Dowty established a wholly owned manufacturing plant in Suzhou, initially specializing in medium structural components for Messier-Dowty's business and regional jet programs. Since then, production has expanded to include work share on the A320 and the 787 (“Operations—Suzhou”). In late 2005, Safran component Snecma established a wholly owned production facility in Suzhou. The facility specializes in the production of turbine and compressor shafts, LP turbine guide vanes (second stage) and LP turbine rings (first stage), as well as the assembly of Module 13 for the CFM56-5B and CFM56-7B engines (“Worldwide—Snecma Suzhou”). In 2008, the Messier-Dowty and the Snecma plants both moved into a new shared facility in Suzhou.

Other Sources of Western Aerospace Technology

In December 2009, AVIC subsidiary XAIC acquired a 91.25-percent share of FACC, for an undisclosed amount. FACC supplies the interior cabin components for the COMAC ARJ-21 and C919 airliners. This was the largest acquisition by a Chinese enterprise in central Europe and reportedly also the first Chinese acquisition of a European aerospace manufacturer. Xi'an plans to establish a composite-materials R&D center built around Fischer in Europe, while setting up produc-

tion facilities in China to take advantage of China's low labor costs ("Xi'an Aircraft Acquires Austrian Company FACC," 2009, p. 10).

Xi'an will reportedly inject at least €40 million (\$58 million) in fresh equity into FACC. Prior to the acquisition, FACC almost doubled its net loss, to €19.6 million, in fiscal year 2008–2009 ("China's XAC Buys Plane Parts Maker FACC," 2009).

There is also at least one instance of a Western aerospace company acquiring partial ownership of a company in China's aerospace sector: EADS holds a 5-percent stake in AviChina, a Hong Kong-listed subsidiary of AVIC engaged in the international marketing of AVIC helicopters, trainers, and other light aircraft. However, this appears to be primarily a joint-venture marketing effort rather than a true cross-holding relationship between AVIC and EADS. Currently, no other Western aerospace company appears to have acquired ownership stakes in any Chinese aerospace company, but the Chinese government has been pushing to increase the number of publicly listed aerospace companies in China, and such relationships may increase in the future.

China's Space Capabilities

Like aviation technologies, many space technologies are inherently dual-use. The development of capabilities to produce civilian space systems, therefore, contributes to China's capability to produce military space systems. Launch vehicles can be used to launch military as well as civilian satellites, and communications, weather, earth-observation, and navigation satellites can be used for military or civilian purposes. Military missiles, even ballistic missiles, generally use different types of rocket motors and launch methods than space launch vehicles, but certain components, such as guidance and control systems, may be similar.

Foreign involvement in China's space industry is significantly less than in the aviation manufacturing industry. China is not closely integrated into the supply chains of foreign space companies, and the market for Chinese products and services such as space launches and satellites is small. Although China's space launch vehicles were originally based on ballistic-missile technology transferred from the Soviet Union, China has advanced far beyond that technology through its own efforts, and foreign assistance has been limited. Chinese space companies have received technical assistance from foreign entities in some specific areas, such as Russian assistance in the area of manned space-flight, Brazilian assistance in the development of earth-observation satellites, German assistance in the development of communications satellites, and U.S. assistance in launch-vehicle technology. In most cases, however, the advancement of China's space technology has been the result of purely domestic efforts.

China has made significant progress in advancing its space capabilities over the past decade and is making concerted efforts to further expand them. All relevant metrics reveal an accelerating growth trend in the country's civilian and military space program development. In 83 known spacecraft launches between October 20, 1996, and June 15, 2010, Chinese launch vehicles experienced only one failure—an incomplete burn of a third stage that resulted in an Indonesian communications satellite being put in the wrong orbit in August 2009 (“Long March [Chang Zheng],” 2010). The 83 launches included three successful launches of manned spacecraft, the most recent of which, in September 2008, involved a spacewalk, and two lunar orbiters (“Shenzhou Series,” 2009; “Chang’e Series,” 2010).

China's government is trying to promote China's growth as a provider of commercial space products and services. In the 1990s, China emerged as a major provider of commercial launch services with its Chang Zheng (“Long March”) series of launch vehicles. From 1990 to 1999, Chinese rockets launched nearly 30 satellites for customers based outside of mainland China. In the late 1990s, however, several Chang Zheng launches failed, and it was revealed that U.S. satellite companies had provided technical assistance to Chinese launch-vehicle-makers (who also make missiles for the Chinese military and for export), resulting in tightened U.S. restrictions on China launching satellites that contain U.S. technology. As a consequence, only a handful of launches have been conducted for customers based outside of mainland China since 1999 (“Long March [Chang Zheng],” 2010). Recently, however, China has developed a domestically designed communications satellite, the European company EADS Astrium has developed a communications satellite that contains no U.S. technology, and as noted above, Chinese launch vehicles have established a remarkable record for reliability since 1996. As a result, the appeal of Chinese space products and services in markets outside the United States is probably increasing. China's 11th Five-Year Plan, which ended in 2010, called for the greater integration of market mechanisms into the space program to foster competition and to generate products and services that could earn China a larger share of the global commercial space-systems market (“Aerospace Development 11th 5-Year Plan”).

A separate policy document, the “National Guidance for Medium- and Long-Term Plans for Science and Technology Development (2006–2020),” outlines further goals for the Chinese aerospace industry. Objectives listed in the document include developing nontoxic, pollution-free, high-performance, low-cost, powerful-thrust launch vehicles capable of carrying 25-ton payloads into low earth orbit (LEO) and 14-ton payloads into geostationary orbit (GEO)¹; developing a 120-ton-thrust liquid-oxygen/kerosene engine and a 50-ton-thrust hydrogen-oxygen engine; improving and developing remote-sensing satellites and associated ground stations; further developing communications- and broadcast-satellite technologies; pushing toward commercialization of communications- and broadcast-satellite services; increasing the number and quality of space technology experiments; and developing a deep space telescope (“China’s Space Activities in 2006,” 2006).

China has maintained a relatively high launch tempo of about one launch every two months, on average, for the past decade and is steadily increasing its total number of orbiting operational satellites. At the end of 2002, China had nine satellites in orbit (Guo, 2002). Today, it has an estimated 55 operational satellites, not including communications satellites owned and operated out of Hong Kong. Additionally, since 2002, there have been five recoverable photoreconnaissance satellite missions, three manned missions (manned spaceflight program), and two lunar observation missions, and a commercial communications satellite was successfully built and launched for Venezuela (“UCS Satellite Database”; “Long March [Chang Zheng],” 2010; “Chang’e Series,” 2010).

Nonetheless, China’s space program has encountered significant technical problems, particularly with satellites. China’s domestically designed high-capacity communications satellite platform, called

¹ LEO is generally defined as the region from the lowest altitude at which an object can be maintained in orbit (about 160 km) up to about 2,000 km. GEO is an orbit in which the satellite orbits in the same plane as the earth’s equator and at an altitude such that it revolves around the earth at the same angular rate as the earth’s rotation (42,164 km). This results in the satellite appearing to hover over a fixed location on the earth’s equator, hence the term “geostationary.” Most communications satellites are in GEO.

Dongfanghong 4 (DFH-4), has experienced multiple failures. The Huanjing series of environmental and disaster-monitoring satellites and the Haiyang series of oceanographic satellites, although they have experienced no known failures, are being deployed more slowly than originally announced. Three out of 10 Beidou-series PNT satellites have also experienced technical problems. It is not clear whether these problems are due to underlying design issues, insufficient quality control in construction, or simple poor luck, but China's space capabilities will probably not develop as quickly as outlined in the "National Guidance for Medium- and Long-Term Plans for Science and Technology Development (2006–2020)." Nonetheless, comparison with the successes of China's space program suggests that any technical problems will be overcome eventually. The ultimate effect on U.S. national security will be the same, but that effect might not emerge as quickly as current plans would imply.

Despite some technical setbacks, Chinese satellites now provide increasingly sophisticated intelligence, surveillance, and navigation capabilities that have significantly advanced China's military capabilities. Though the capabilities of the satellites fall short of U.S. standards, they are more than sufficient for most military purposes. China's commercial space prospects seem more limited given extensive foreign competition, but its space launch program has achieved a number of successes that make it potentially appealing to other countries interested in launching commercial satellites.

Launch Vehicles

All of China's operational space launches have been performed by the Chang Zheng (CZ) family of rockets, although China is apparently developing a family of small solid-fuel launchers called Kaituoze (Pioneer). The design of the CZ family was based on the Dongfeng series of ballistic missiles developed in the 1960s. The first CZ rockets were launched in 1969 (that rocket failed), 1970, and 1971 from Jiuquan Space Launch Center. There are currently three operational series of CZ missiles: CZ-2, CZ-3, and CZ-4. All use liquid-bipropellant-fueled

engines, and all can be launched from one of China's three currently operational launch sites. The most powerful versions are capable of carrying at least 8,000 kg (the weight of the Shenzhou manned space modules) into LEO and more than 5,000 kg into GEO. As of June 2010, there had been 125 launches of the CZ series ("Long March [Chang Zheng]," 2010; "Shenzhou Series," 2009).

The next generation of CZ rockets, the CZ-5 series, is currently under development and is expected to enter service by 2014. The CZ-5 is being manufactured in Tianjin and will be delivered by sea to the Wenchang Space Launch Center, which is currently under construction on Hainan Island. The CZ-5 will use nontoxic fuels and is intended to be able to lift 25-metric-ton payloads into LEO and 14-ton payloads into GEO ("Long March 5 [CZ-5] Series," 2010).

The Kaituozhe is a solid-fuel rocket based on the Dongfeng-21 ballistic missile. Development of the launch vehicle began in 2000. Three versions—KT-1, KT-2, and KT-2A—are reportedly in development. The KT-1 is believed to have flown at least five times, but at least two of the test flights were failures ("Kaituozhe Series," 2010). At one time, the launch vehicle's manufacturer, China Aerospace Science and Industry Corporation (CASIC), was actively marketing the Kaituozhe, but as of October 2010, no reference to it could be found on CASIC's website.

Satellites

Communications Satellites

Currently, about nine operational commercial communications satellites are owned and operated by organizations based in mainland China (another two or three are owned and operated by companies based in Hong Kong). Only two of these satellites, however, were manufactured by Chinese companies. China also operates two military communications satellites and one data-relay satellite, all of which were manufactured by Chinese companies ("UCS Satellite Database").

Dongfanghong 3

Dongfanghong (“East is Red”) 3 (DFH 3) is a medium-capacity communications satellite built by the Chinese Academy of Space Technology (CAST), a subsidiary of China Aerospace Science and Technology Corporation (CASC), a state-owned company. The first DFH 3 was orbited in 1994 (“Long March [Chang Zheng],” 2010). Four satellites based on this design are currently in operation: ChinaSat 5C, a commercial communications satellite; Fenghuo and Shentong, military communications satellites; and Tianlian, a data-relay satellite.

ChinaSat 5C, formerly known as Sinosat 3 or Xinnuo 3, was launched on May 31, 2007. It is operated by China Satellite Communications Corporation (China Satcom), a subsidiary of CASC, and carries 10 C-band transponders that provide television services throughout China (“ChinaSat 5C”).

Fenghuo and Shentong are dedicated military communications satellites. Fenghuo, officially known as Zhongxing 22 or ChinaSat 22, was reportedly developed by CAST to support a theater-level command, control, communications, and intelligence network called Qudian. The first Fenghuo satellite, Fenghuo 1, was launched in January 2000. A replacement, Fenghuo 1A (Zhongxing 22A/ChinaSat 22A), was launched in September 2006. The original Fenghuo appears to no longer be functional. Fenghuo 1A provides secure voice and data communications (“Feng Huo [Zhongxing 2X/ShenTong Series],” 2010; “UCS Satellite Database”).

Shentong, officially known as Zhongxing 20 or ChinaSat 20, is described as a “strategic communications” satellite and was launched in November 2003. It is reportedly the first Chinese satellite to use multiple steerable Ku-band spot-beam antenna technology, which enables ground users to communicate at high data rates while on the move, and the first to use secured uplink transmission for satellite antenna control; it reportedly has China’s most powerful onboard data-processing capability (“Feng Huo [Zhongxing 2X/ShenTong Series],” 2010).

China launched its first data-relay satellite, Tianlian 1, in April 2008, putting it into GEO at 77 degrees east. Tianlian is based on a DFH-3 bus. It was launched in preparation for the Shenzhou 7 manned mission, which occurred in September 2008, and is reportedly

the first in a new network that will augment or replace China's current ground-based space-tracking and telemetry stations and space-tracking ships. Tianlian is referred to as a "space station" for relaying data ("China Sets Up First Space Station for Spacecraft Data Relay," 2008). China's space-tracking ships and ground stations were able to cover only 12 percent of Shenzhou 7's orbit, according to Zhang Jianqi, a top Chinese space official quoted by Xinhua ("China Blasts Off First Data Relay Satellite," 2008).

In addition to providing communications with manned spacecraft, data-relay satellites can also provide relay services for other satellites. Because of the curvature of the earth, a satellite in LEO at an altitude of 600 km, such as China's Yaogan series of military reconnaissance satellites, can communicate only with ground sites within about 2,800 km of its location. If there are no ground stations within that distance at the time the satellite collects an image, it must store the data until it comes within range of a ground station. For example, a Chinese reconnaissance satellite passing over Guam would have to store any images it collected until it passed within range of a Chinese ground station. A satellite in GEO, however, can communicate with a ground station or other satellite virtually anywhere on about one-third of the earth's surface. Thus, a reconnaissance satellite in LEO could transmit images it collects up to a satellite in GEO, which could then immediately relay them back down to a ground station in China, where they could be processed (if the reconnaissance satellite was far away from China, more than one relay satellite might be needed). Tianlian 1 is located off the southern tip of India and thus is not ideally positioned to act as a relay for Chinese satellites passing over the western Pacific region, but in the future, China will likely deploy additional relay satellites.

Dongfanghong 4

Dongfanghong 4 is a high-capacity communications satellite, also built by CAST. This design has experienced significant technical problems. The first example, SinoSat 2, was built for Sino Satellite Communications, a Chinese state-owned company now absorbed into China Satcom. Sinosat 2 was launched in October 2006, but its solar panels

failed to deploy, and the satellite was a total loss. The second example, NigcomSat, was built for the Nigerian government and launched in May 2007. The drive on one of its solar arrays failed, and the satellite is apparently no longer operational. The third example, Venesat 1, was built for the Venezuelan government. It was launched in October 2008 and is apparently operating normally. The fourth and most recent example, ChinaSat 6A (also called Sinosat 6), was launched on September 4, 2010, to act as a backup for ChinaSat 5C (described above). However, ChinaSat 6A suffered a leak in its helium-pressurization system that will likely shorten its operational life from a design goal of 15 years to at most 10 years (Covault, 2006; "NigComSat," 2010; "UCS Satellite Database"; "Venesat (Simon Bolivar)," 2010; "Chinasat/Zhongxing/STTW Series," 2010; de Selding, 2010).

Weather Satellites

China launched its first weather satellite, Fengyun 1A, in 1988. Since that time, it has launched 10 additional Fengyun ("Wind and Cloud") satellites of increasing capability. As of July 2010, five of these were apparently still operational: Fengyun 1D, 2C, 2D, 2E, and 3A.² Fengyun 1D is in a polar LEO and has a 10-channel radiometer operating in the visible and infrared bands for observation of clouds, land surfaces, and oceans. Fengyun 2C, 2D, and 2E are in GEO and carry radiometers operating in five channels ("Fengyun Series," 2010; "UCS Satellite Database").

Fengyun 3A, launched in May 2008, is the first of a new generation of polar weather satellites that is much more capable than the Fengyun 1 series. It carries a 10-channel scanning radiometer, infrared and microwave radiometers, a space environment monitor, and an earth-radiation scanning radiometer. It provides images with a spatial resolution of 250 m and temperature accuracy of 0.1°F. Two more satellites in the Fengyun 3 series were expected to be launched in 2008, but as of July 2010, only Fengyun 3A was in orbit. The reasons for the delay are unclear ("Fengyun Series," 2010; "UCS Satellite Database").

² Fengyun 1C, which had already ceased functioning, was destroyed in a ground-launched antisatellite weapon test in January 2007.

China is also developing a Fengyun 4 series GEO satellite to replace the Fengyun 2 series. Reportedly, there will be an optical series and a microwave series. The launch of the first optical satellite is expected in 2012, followed by two more in 2015, then two more in 2019. The first of the microwave series is scheduled for 2015, followed by another in 2018 and a third in 2022 (“Fengyun Series,” 2010).

Weather satellites have both civilian and military utility. Knowing and predicting weather can be crucial to successful military operations. Indeed, China's military reportedly plans to use the Fengyun 3 satellites for military weather forecasting, and the United States still maintains its own Defense Meteorology Satellite Program satellites. Weather satellite data is increasingly a global public good, and China, as a member of the World Meteorological Organization, has access to data from other countries' civilian weather satellites. Having its own weather satellites, however, provides China with a hedge against a cutoff of this information in the event of a confrontation with the United States or other countries (“Fengyun Series,” 2010; “Defense Meteorology Satellite Program [DMSP] Series,” 2009).

Civilian Earth-Observation Satellites

China operates three series of earth-observation satellites that are primarily or exclusively civilian in purpose. The oldest series is the China-Brazil Earth Resources Satellites (CBERS) series, jointly developed with Brazil. China also operates the Haiyang series of oceanographic satellites and the Huanjing series of environmental and disaster-monitoring satellites.

CBERS

The stated mission of the CBERS is to provide imagery of the earth's surface for applications including agriculture, environmental protection, hydrological and ocean resources, forestry, and geology. Three CBERS have been launched since 1999. At the moment, apparently only the third, CBERS 2B, launched in September 2007, remains in operation, but at least two additional satellites are planned. The satellites have multisensor payloads with different spatial resolutions and image-collecting frequencies, including a wide field imager (WFI),

a charge-coupled-device (CCD) camera, and a high-resolution panchromatic (i.e., black-and-white) camera (HRC).³ Brazil developed the WFI, while China developed the CCD camera and the HRC.⁴ The onboard WFI has a ground swath of 890 km at a spatial resolution of 260 m in two spectral bands. The CCD camera provides images of a 113-km-wide swath with 20-m spatial resolution in five spectral bands and is capable of taking stereoscopic images. The HRC provides images of a swath 27 km wide with a resolution of 2.7 m. Images from the WFI and CCD cameras are available to the public; images from the HRC are not ("China-Brazil Earth Resources Satellites [CBERS]/Ziyuan Series," 2009; "Zi Yuan CBERS [China-Brazil Earth Resources Satellite]," "CBERS: China-Brazil Earth Resources Satellite").

Images with 20-m resolution, such as those provided by the CCD camera on CBERS 2B, are too coarse to be militarily useful, but images with 2.7-m resolution, such as those provided by the HRC, can be militarily useful. For example, 2.7-m resolution is sufficient to identify ship or aircraft types and thus would enable an analyst to determine whether a ship was an aircraft carrier or a cargo ship, or whether fighter aircraft were present at an airbase. Thus, it is interesting that images from the HRC, unlike those from the WFI and CCD camera, are not publicly available.

Huanjing

The Huanjing ("Environment") series satellites are described as environmental and disaster-monitoring small satellites. Two of a planned 11 had been launched as of July 2010. Both were launched atop a single launch vehicle in September 2008, and both are equipped with a CCD camera of 20-m resolution. Huanjing 1A also carries a multispectral (visible and infrared) radiometer with 100-m resolution. Huanjing 1B carries an infrared camera with 150-m resolution. A third satellite, Huanjing 1C, which was expected to launch in 2010, carries an S-band (2–4 GHz) synthetic aperture radar (SAR) capable of seeing through clouds and at night with a resolution of 20 m. As noted above,

³ See "Zi Yuan CBERS (China-Brazil Earth Resources Satellite)."

⁴ See "CBERS: China-Brazil Earth Resources Satellite."

images of 20-m resolution have limited military utility. Thus, the current Huanjing satellites cannot make a significant contribution to China's military capabilities ("UCS Satellite Database"; "Huanjing Series," 2010).

Haiyang

The Haiyang ("Oceans") series satellites are officially ocean-observation satellites intended for monitoring of oceanic resources, port building, and environmental and pollution study. Currently, the second satellite in the series, Haiyang 1B, launched in April 2007, is operational. The first, Haiyang 1A, was launched in 2002 and is no longer operational. Haiyang 1B carries a 10-channel infrared scanner with resolution of 1.1 km and a four-band CCD camera with maximum resolution of 250 m. These satellites are controlled by the State Oceanic Administration and have little or no military utility, but reportedly a Haiyang 2 series and Haiyang 3 series are under development. Instruments carried by the Haiyang 2 series will include an altimeter to measure sea surface height, which, depending on the capability of the instrument, could theoretically be used to attempt to detect the presence of submerged submarines. The Haiyang 3 series, the first of which is expected to be launched in 2012, will reportedly carry a radar that operates in the X-band (8–12 GHz) and is capable of obtaining images of land and ocean features (e.g., ships) with resolution as fine as 1 m. The Haiyang program appears to be behind schedule, however. The first satellite of the Haiyang 2 series (Haiyang 2A) was originally said to be planned for launch in 2009. As of July 2010, however, only Haiyang 1B was in orbit ("UCS Satellite Database"; "Haiyang Series," 2010; Pollpeter, 2008, p. 21).

Military Imagery Reconnaissance Satellites

China has three series of military imagery satellites. The oldest are the Fanhui Shi Weixing (FSW) recoverable film satellites. These have been followed by the Ziyuan and, most recently, Yaogan series.

FSW

Five different models of FSW (“Recoverable Satellite”) satellites have been developed (corresponding to the military designators Jianbing 1, 2, and 4). The first launch was attempted in 1974, but it failed. The first successful launch took place in 1975. Since that time, 21 additional missions have been flown, the most recent in 2005. The most recent missions lasted 18 to 27 days. Presumably, the advantage of the FSW satellites, even though China is now able to produce satellites with high-resolution CCD cameras, is that the shortness of the mission dictated by the limited quantity of film that can be carried allows the satellites to be flown in lower, quickly decaying orbits. For example, as noted above, the Yaogan series orbit above 600 km. The most recent series of FSW missions, by contrast, flew in orbits that varied between about 200 km and 320 km, or between 165 km and 550 km. Orbits this low cannot be maintained for long periods of time because of the atmospheric drag, but since the film in the cameras is apparently exhausted after 18 to 27 days, this is not a problem for the FSW series. And since resolution is a linear function of range, a satellite orbiting at 300-km altitude can collect images with twice as high resolution as a satellite orbiting at 600-km altitude (“Fanhui Shi Weixing 3 [FSW-3]/JianBing-4 Series,” 2010).

Ziyuan

Three satellites in the Ziyuan (“Resources”) series have been launched, the first in September 2000 and the last in November 2004. They are officially the Chinese domestic equivalent of the CBERS series and are said to be designed for civilian roles such as territorial surveying, environment monitoring, city planning, crop-yield assessment, disaster monitoring, and space-science experimentation. However, the Chinese government has never released any information concerning their design or the imaging systems they carry, and they are believed to in fact be military imagery reconnaissance satellites with the military designation JianBing-3. All three are believed to carry CCD cameras with approximately 3-m resolution and infrared multispectral scanners. They reportedly have design lives of two to four years, but as of

July 2010, all three were apparently still in operation (“UCS Satellite Database”; “ZiYuan-2/JianBing-3 Series,” 2010).

Yaogan

Yaogan (“Remote Sensing”) is China’s most recent generation of imagery reconnaissance satellites. It appears to comprise at least two types—SAR satellites (military designator JianBing 5) and optical-reconnaissance satellites (military designator JianBing 6)—and possibly a third type, an ocean-surveillance satellite.

Ten Yaogan satellites have been launched to date. Yaogan 1, launched in April 2006, was China’s first SAR-equipped satellite. Since that time, three additional SAR satellites in the Yaogan series have been launched: Yaogan 3, 5, and 10. The satellites’ radar reportedly operates in the L-band (1–2 GHz) and has resolution as low as 5 m. Yaogan 1 apparently broke up in February 2010, but Yaogan 3, 5, and 10 remain operational (“Yaogan Series,” 2010; “UCS Satellite Database”).

Yaogan 2, 4, 6, 7, and 8 are believed to be optical-reconnaissance satellites with resolution of possibly 0.8 m. Yaogan 2 was launched in May 2007, and all five of these satellites are apparently still operational (“Yaogan Series,” 2010; “UCS Satellite Database”).

Yaogan 9, launched in March 2010, may be an ocean-reconnaissance satellite. It consists of a main satellite and two subsatellites in nearly identical orbits. This configuration resembles that of the U.S. Navy’s Naval Ocean Surveillance Satellite system. The satellites reportedly carry infrared sensors to detect ships and antennas to pick up electronic emissions. The use of three satellites would enable the location of an electronic emitter to be determined through triangulation (Parsons, 2010, p. 14; “Yaogan Series,” 2010).

Position, Navigation, and Timing Satellites

The impetus for developing an indigenous PNT system was first military, then commercial. Many Chinese weapon systems use GPS to increase their accuracy, but Chinese military leaders, fearing that GPS could be degraded or shut down in a conflict, concluded that they needed their own independent PNT system (Pollpeter, 2007).

The Beidou ("Northern Dipper")/Compass system is China's indigenously developed PNT satellite system. It is intended to serve as an alternative to GPS, the Russian Glonass, and the European Galileo system. In 2000, China launched the first satellites of a first-generation PNT constellation using satellites in GEO. The system provided coverage only over East Asia, positioning accuracy was only about 100 m, and, because the system required two-way communication between the users and a central control station, the user equipment was bulkier and required greater power than the U.S. GPS system, in which the user equipment consists of passive receivers ("Beidou/Compass Series," 2010).

Although two of the original Beidou satellites remain operational (Beidou 1B and 1C), in 2007, China began deploying the first satellites of a second-generation system, called Compass or Beidou 2. This system, like GPS, will be a one-way passive system with global coverage. Unlike GPS, however, which includes only satellites in medium earth orbit (MEO), Compass will include satellites in a combination of MEO and geosynchronous orbit (GSO).⁵ The system will provide commercial customers with positioning accuracy to within 10 m and timing accuracy (needed for the synchronization of automated datalinks) to within 10 nanosec. Greater accuracy will be available to Chinese military users ("UCS Satellite Database"; "Beidou/Compass Series," 2010).

By August 2010, four operational Beidou 2 satellites were in orbit (one in inclined GSO, two in GEO, and one in MEO). Twelve satellites are planned to be in orbit by 2012, providing a regional navigation system covering China and its neighboring areas. A complete system of 35 satellites is intended to be in place by 2020. These will include five satellites in GEO, 27 in MEO, and three in inclined GSO ("UCS Satellite Database"; "Beidou/Compass Series," 2010).

The satellites appear to be experiencing technical problems. In February 2007, one of the four first-generation Beidou satellites

⁵ GSO is an orbit in which the satellite is at an altitude (42,164 km) such that it revolves around the earth at the same angular rate as the earth's rotation but is not necessarily in the same plane as the earth's equator. Thus, GEO is a special type of GSO.

(Beidou 1D) experienced an explosion while transiting to GEO, then it had trouble deploying its solar panels after reaching GEO. Finally, in February 2009, its orbit was raised by 130 km in an apparent attempt to place it in a “graveyard” orbit (an orbit in which nonfunctional satellites are placed, where they will not interfere with operational satellites). The first of the new generation of geostationary spacecraft (Beidou 2B/Compass G2) apparently lost control after being launched in April 2009. In April 2010, an analysis was published stating that there were frequent spikes in the signal from the first MEO Compass satellite, suggesting that there is a problem on the satellite. Thus, three out of nine Beidou satellites launched so far have experienced technical problems (“Beidou/Compass Series,” 2010).

Commercial applications of Beidou are also having trouble getting off the ground. A receiver unit for the first-generation Beidou system costs about \$2,500, more than 10 times the cost of a GPS unit (Pollpeter, 2007). It is unclear how much a receiver for the second-generation system, which is not yet operational, will cost. In any case, since there is no charge to use the public GPS signal, Beidou seems unlikely to displace GPS in commercial applications, except perhaps in China. It is possible, however, that commercial navigation systems could eventually employ Beidou as a supplement to GPS signals.

Other Satellites

Shijian

The Shijian (“Prototype”) series is a long-running space-science and technology demonstrator program. The first satellite in the series, Shijian 1, launched in 1971, was the second satellite launched by China (the first, launched in 1970, was called Dongfanghong and carried only a radio transmitter). Currently, nine satellites in the series are operating: Shijian 6A, 6B, 6C, 6D, 6E, 6F, 7, 11-01, and 12. The Shijian 6 series was launched into LEO in three pairs between September 2004 and October 2008. According to the Chinese government, the Shijian 6 mission is “exploration of space environment, radiation in space and their influence, parameters of physical environment of the space, and other related space experiments” (“Shijian Series,” 2010). However, few details about the satellites have been revealed by Chinese media,

and the launch dates have been announced only 24 hours in advance. Some sources reportedly suspect that they are signals-intelligence or electronic-intelligence satellites ("UCS Satellite Database"; "Shijian Series," 2010).

Shijian 7, launched in July 2005, is in an orbit that is similar, albeit somewhat lower, than that of the Shijian 6 series (555 km \times 570 km vs. 590 km \times 605 km). Shijian 11-01, launched in November 2009, is in a distinctly higher orbit (690 km \times 705 km). As is the case with the Shijian 6 series, little information about Shijian 7 and Shijian 11-01 has been released, other than to say that they will monitor the space environment and/or conduct space-science and engineering experiments ("UCS Satellite Database"; "Shijian Series," 2010).

Shijian 12 was launched, on similarly short notice, in June 2010. Over the following two months, it was maneuvered into an orbit nearly identical to that of Shijian 6F, and on August 19 it approached Shijian 6F so closely that it may have actually made contact with it, the first known instance in which a non-U.S. satellite has conducted such a rendezvous (the United States has conducted similar operations in the past). Such a capability has multiple potential applications, such as clearing space debris, inspecting and repairing satellites, or docking with a space station such as the Tiangong module that China plans to put up next year. Another possibility, however, would be to damage or interfere with an enemy satellite ("Shijian Series," 2010; Courtland, 2010).

Other recent satellites in the Shijian series are Shijian 5, launched in May 1999, and Shijian 8, launched in September 2006 (no information is available on a Shijian 9 or 10, if they exist). Shijian 5 was apparently a test of a modular minisatellite platform to be used for various applications, although objectives of the mission reportedly also included measurement of high-energy particles in near-earth space and a microgravity fluid-physics experiment. The satellite is no longer operational. Shijian 8 was officially a recoverable microgravity seed-growing mission (using the same recoverable capsule used by China's FSW film reconnaissance satellites) designed to study the effects of radiation and microgravity on different varieties of fruit and vegetable seeds, fungi, and molecular biomaterials. No information is available on whether

the mission had additional purposes. The recoverable capsule returned to earth after 15 days, and the satellite reentered the atmosphere in November 2006 ("Shijian Series," 2010)

Beijing 1 (DMC-4, Tsinghua-2)

Beijing 1 is an earth-mapping small satellite, built in cooperation with Surrey Satellite Company of England and launched in October 2005. It carries the China Mapping Telescope, with a resolution of about 4 m ("Europe's Student-Built Satellite Rockets into Space," 2005). Another imaging camera on board has resolution of 32 m. The satellite weighs 150 kg. As of July 2010, it was apparently still in operation ("China DMC+4 Satellite Launched, Carries 4 m Resolution Camera," 2005; "UCS Satellite Database").

Chuangxin

Chuangxin 1, launched in October 2003, is a mini "store and forward" communications satellite. It was developed by CAS, the Shanghai Academy of Space Technology (SAST, a subsidiary of CASC), and Shanghai Telecom. The project has been carried out jointly by researchers from the CAS Shanghai Institute of Microsystem Information Technology and the CAS Shanghai Institute of Technical Physics ("Small Satellite Launch Successful," 2003). Chuangxin 1 was launched piggyback with CBERS-2 in 2003 and weighs less than 100 kg ("CBERS 2 and Chuangxin 1 to Be Launched on 21st or 22nd," 2003). CAS claims that it will serve a range of functions by providing data communications for such sectors as traffic and transportation, environmental protection, oil and gas transportation, flood and drought control, detection of forest fires, and earthquake monitoring. As of July 2010, it was apparently still in operation ("UCS Satellite Database"; "Small Satellite Launch Successful," 2003).

A second satellite in the series, Chuangxin 2, was launched in November 2008 and was apparently still in operation as of July 2010 ("UCS Satellite Database"). Information on its nominal purpose was not available.

Shiyan

The Shiyan (“Test”) satellite (also called Tansuo or Experimental Satellite) is the first Chinese satellite capable of stereo earth-terrain mapping. Its applications are allegedly civilian in nature, but the test of its systems is said to be useful for military reconnaissance spacecraft under development. Shiyan 1, launched in April 2004, is relatively light at 204 kg. No word was given about its development before launch. It is said to have a 10-m stereo resolution observation capacity, developed with input from Astrium. It was developed by CAS, the Research Institute of Space Technology, Xi’an Surveys and Designs Institute, Harbin Polytechnic University, and Changchun Photomechanical Institute. A second satellite in the series, Shiyan 2, launched in November 2004, is larger at 300 kg, and descriptions of its mission are vague. A third satellite, Shiyan 3, was launched in November 2008. Information on its nominal purpose is not available. As of July 2010, all three satellites were apparently still in operation (“China Launches Two New Satellites,” 2004; “Experimental Satellite #1 and Naxing #1 Sent into Space,” 2004; Hitchens, 2006, pp. 12–13; “UCS Satellite Database”).

Naxing

Naxing 1 is an experimental 25-kg “nanosatellite” launched piggyback with Shiyan 1 in April 2004 and said to be used to conduct “some high-tech experiments.” Little is known about its full functions. It is the world’s smallest satellite with three-axis stabilization. As of July 2010, it was apparently still in operation (“Naxing 1”; Johnson-Freese, 2005, p. 8; “UCS Satellite Database”).

Zheda Pixing

Zheda Pixing 1, a “picosatellite” developed by Zhejiang University and Shanghai Institute of Microsystems and Information Technology, CAS, was launched in May 2007. It has no moving parts and no attitude control and weighs only 2.5 kg. It is designed for microelectronic mechanical systems (MEMS) experiments for systems such as accelerometers, microgyros, and infrared sensors. Little else is publicized about its mission or specifications. As of July 2010, it was apparently still in operation (“UCS Satellite Database”).

On September 22, 2010, two additional satellites in the series, Zheda Pixing 1B and Zheda Pixing 1C, were launched. They, too, are said to have been developed by Zhejiang University “for microelectronics studies to provide a testbed in near-earth space for MEMS devices, such as an accelerometer, micro-gyros and infrared sensors” (“Zheda Pixing 1B”).

Xiwan 1

Xiwan 1 (“Hope 1”) is a 50-kg Chinese amateur-radio satellite launched as a secondary payload with Yaogan 8 in December 2009 (“Yaogan Series,” 2010).

Double Star

The Double Star (Tan Ce) dual satellites are part of a cooperative venture with the European Space Agency (ESA) to conduct space-science experiments. Their mission is to study the earth’s magnetic field and particle environment, operating in concert with ESA’s four Cluster spacecraft. Double Star 1 burnt up on reentry in 2007, but Double Star 2 was apparently still in orbit as of July 2010, although its mission was said to have been terminated (“Double Star [Tan Ce],” 2010; “UCS Satellite Database”).

Assessment

China’s space capabilities have made remarkable progress over the past two decades. Its satellite capabilities, in particular, have gone from rudimentary to near-state-of-the-art in some areas. Prior to 1988, the only satellites China had orbited other than experimental satellites were recoverable film reconnaissance satellites and low-capacity telecommunications satellites. Since that time, however, China has successively developed and deployed a series of weather satellites, medium-capacity communications satellites, electro-optical reconnaissance satellites, PNT satellites, ocean-surveillance satellites, SAR satellites, high-capacity communications satellites, and possibly signals-intelligence or

electronic-intelligence satellites. The capacity and reliability of China's space launch vehicles have increased as well.

The space capabilities China now possesses have the potential to significantly increase the effectiveness of its military operations. China's seven optical reconnaissance satellites (eight, if CBERS 2B is counted) are in orbits that cause them to revisit locations every three to six days, meaning that one or two of them are likely to pass over a given location each day. These satellites have sufficient resolution to detect and identify types of ships, aircraft, and ground vehicles. One of China's three SAR reconnaissance satellites, which are equally effective at night, is also likely to pass over a given location once or twice a day. These satellites likely have lower resolution than China's optical-reconnaissance satellites, but they are not significantly affected by the presence of clouds and likely have sufficient resolution to at least determine the presence of aircraft at an airfield and distinguish broad types of ships (e.g., aircraft carriers from cargo ships). Finally, if the Shijian 6 series and Yaogan 9 satellites are indeed electronic-intelligence satellites, then they can detect and identify radio-frequency emitters such as radio communications equipment and radar based on their frequency and waveforms.

These reconnaissance satellites could have several effects. Their ability to identify the locations, numbers, and types of enemy forces will reduce the ability of adversaries to achieve operational surprise against China, since China will be able to detect the massing of forces; it will also enable the Chinese military to more effectively conduct its own attacks. For example, China could use its satellites to determine the presence of aircraft on the ground at an airbase and launch a combined air and missile attack against them. The satellites could also enable China to determine the presence and locations of land-based air and missile defense systems (e.g., Patriot) and avoid or neutralize them before launching air and missile attacks on other targets. Similarly, China could use them to locate and attack mobile radio transmitters and command posts, reducing an adversary's ability to command and communicate with its forces. Finally, in combination with other systems, such as over-the-horizon radar, reconnaissance satellites could be used to find and locate ships at sea, such as aircraft carriers, and then

attack them with a variety of weapons, including the anti-ship ballistic missile China is developing. Once an attack has been conducted, moreover, China's satellites could be used to assess the effectiveness of the attack and whether additional attacks were needed.

PNT satellites provide a number of important military capabilities. They can be used as the guidance systems for missiles, gravity bombs, and other types of weapons, enabling all-weather near-precision attacks. They can also be used to guide ships, aircraft, and ground vehicles, enabling precise navigation and maneuvers. Moreover, if Chinese vehicles are equipped with PNT satellite receivers and radio transmitters that rebroadcast their coordinates, that information could be used as the basis for an identification system. Knowing the locations of friendly units would allow the identity of tracks acquired by sensors such as radars to be more readily determined, enabling enemy units to be attacked more effectively and reducing the likelihood of attacks on friendly units. Finally, the precise timing signals broadcast by satellites in China's second-generation Compass system can be used to synchronize automated data links, enabling high-volume exchanges of data.

Although publicly available signals from the U.S. GPS system can also be used to support these functions, China's Compass system will likely be able to provide higher-precision position and timing than the public GPS signals. Having its own PNT satellite system, moreover, ensures China against a cutoff of the U.S. public GPS signal, however unlikely that may be (as civilian commerce becomes increasingly reliant on GPS, the economic disruption caused by a shutoff would be significant). Finally, since the Compass system uses different frequencies than the GPS system, China's military could jam GPS frequencies, thus denying the United States or other countries access to the GPS signal without obstructing its own ability to acquire PNT information.

China's communications-satellite capabilities are considerably weaker than its reconnaissance and PNT capabilities. Currently, China has only two dedicated military communications satellites. By comparison, the U.S. military operates approximately 30 such satellites. State-owned corporations based in mainland China control another six or seven communications satellites, which could potentially be commandeered for military purposes in the event of a crisis or conflict, but this

would still provide China's military with far less satellite communications capability than the U.S. military possesses. China has the advantage, however, that for the foreseeable future, the conflicts in which it is likely to become involved would not entail the deployment of significant forces outside of mainland China. Forces operating in China can rely primarily on buried fiber-optic cables, which have far higher communications capacity, for communications connectivity. Buried fiber-optic cables are virtually impossible to jam and are difficult or impossible to find from the air or space, and their above-ground equipment, such as gateways, is easy to hide. Communications satellites occupy known, fixed locations and thus can be jammed, and their tracking and control stations are fixed and easily identified and thus potentially subject to attack. Because fiber-optic cable can carry many times more data than a satellite can, the commercial world has seen a de-emphasis of satellites relative to terrestrial cables (including undersea cables) in recent years. Satellite communications would be important primarily to naval forces at sea and ground forces deployed outside of China's borders (e.g., on Taiwan). Given the still-incomplete process of linking China's forces together using digital information links, moreover, China's limited communications-satellite capacity may be sufficient for the immediate future, and this capacity will likely grow over time.

As noted earlier in this chapter, knowing and predicting weather can be crucial to successful military operations, but having one's own weather satellites is not necessarily critical to this capability. China could rely on data from other countries' civilian weather satellites. Having its own weather satellites, however, provides China with a hedge against a cutoff of such data in the event of a confrontation with the United States or other countries.

In sum, China's military satellite capabilities today are substantial and growing. China possesses at least 10 imagery reconnaissance satellites and possibly six or more electronic-intelligence satellites. Information in unclassified sources indicates that these numbers are similar to the numbers of comparable satellites the United States possesses. However, the capabilities of China's satellites undoubtedly fall well short of those of the United States. For example, China's best optical satellites are estimated to have resolution of about 0.8 m. By comparison, com-

mercial satellite imagery with resolution of 0.41 m is now available, and U.S. intelligence satellites are believed to have even better resolution (Matthews, 2008). Nevertheless, the capabilities of China's satellites are probably sufficient for most military purposes. As noted above, 0.8-m resolution is more than sufficient to detect and identify by type ships, aircraft, and ground vehicles. Greater degrees of resolution are primarily of utility for intelligence-collection purposes, such as measuring the exact dimensions of a missile. Most militaries are more open and transparent than the Chinese military is (or the Soviet military was), however, and much of this type of information is available from open sources. Thus, the qualitative inferiority of China's surveillance and reconnaissance satellites may not significantly impact their military utility, and China may have alternative means to compensate for their shortcomings as strategic intelligence-collection platforms.

China's capabilities in communications, PNT, and weather satellites are less robust than those in surveillance and reconnaissance. Moreover, China has experienced setbacks and delays in many of its satellite programs, most prominently the total loss of two out of four high-capacity communications satellites launched so far and the partial loss of a third. China's weather-satellite program appears to be delayed, and several non-military programs have experienced delays as well.⁶ As argued above, however, probably none of these shortcomings are crucial. China probably needs significantly less satellite-communications capacity than the United States does, can use public GPS signals for PNT purposes, and can augment information collected by its own weather satellites with information collected by the satellites of other countries and made publicly available. Moreover, programs are under way to address many of these shortcomings in the next few years.

China's commercial space prospects appear to be less promising in the near term. The only buyers of China's communications satellites have been Nigeria and Venezuela, countries that may have chosen

⁶ A solar space telescope was originally scheduled to be launched in 2008, and the third satellite in the Huanjing series was to have been launched in 2009, but as of July 2010, neither had been orbited, and several satellites scheduled to be launched in 2010 appeared to be behind schedule as well. See Bodeen, 2007; "China to Launch 10 Satellites in 2008," 2008.

to buy from China for political or cost reasons rather than because of the capabilities of the satellites offered. And as a result of the failure of two of four examples of the DFH-4 platform on which these satellites were based, increased insurance premiums on future purchases of this type may erase much of the cost advantage. Nonetheless, Nigeria has reportedly ordered three more satellites based on the DFH-4 platform ("NigComSat," 2010). If these satellites are successfully launched and operated in the next few years, China's ability to sell such satellites to other countries may improve.

In the area of commercial imagery, China is not known to have offered for sale the high-resolution imagery provided by CBERS 2B or its Ziyuan or Yaogan series of imagery satellites. This may in part be to avoid revealing the capabilities of those satellites, but the Chinese government also does not accept the legitimacy of the satellites of other countries collecting intelligence information on China from space, and it claims that its own satellites do not image the territory of other countries (conversation with Chinese space official, April 2008). Thus, China might have difficulty offering satellite imagery for sale without contradicting its own government's position. In any case, given that higher-resolution commercial imagery is already available from other sources, China's satellites might have difficulty competing in the commercial imagery market.

Finally, once the Compass constellation of PNT satellites is complete, around 2020, it is possible that China could offer access to its high-precision signal on a subscription basis. Given that the public GPS signal is freely available, however, it is not clear how many individuals or organizations would be willing to pay for a higher-precision signal.

Thus, China's strongest and most marketable space capability probably remains its space launch capability. As noted earlier in this chapter, China's space-lift vehicles, although not as powerful as those of the United States, the ESA, or Russia, have compiled a remarkable record of success since 1996. However, because of restrictions the United States imposed in the late 1990s on China's launching of satellites with U.S. technology content, since 1998 only three of those launches have been for foreign customers, and two of those were of NigComSat and Venesat, Chinese-made satellites. Palapa D1, launched in August 2009

for an Indonesian company, however, was built by Thales Alenia Space without using American components and thus was not subject to U.S. export restrictions (“Palapa Series,” 2010). It might represent the leading edge of a new wave of launches of commercial satellites without U.S. technology content, except that, ironically, the launch of Palapa D1 is the one known failure of a Chinese launch vehicle in the past 14 years. Whether Chinese launch vehicles will become popular again for contract launches remains to be seen.

Conclusions

China's aerospace sector has advanced at a rapid, though not unanticipated, rate over the past decade and will continue to advance in future years. At present, however, it still lags behind the state of the art in virtually all areas. Nonetheless, the development of China's civil aerospace sector is unquestionably contributing to the development of its military aerospace capabilities, increasing China's ability and possibly its propensity to use force in ways that negatively affect U.S. interests and would increase the costs of resisting attempts to use such force.

The Rate at Which China's Aerospace Sector Has Developed

Until the creation of COMAC in 2008, all of China's civilian and military aerospace products were produced by China's state-owned defense conglomerates. Even as China's economy was opened up, beginning in the 1970s, these industries remained backward and inefficient, burdened by remaining part of the planned economy and starved for resources. A 2001 RAND study (Cliff, 2001, pp. 24–25), noted

The combat aircraft [produced in China] are mostly based on 1950s and 1960s Soviet technology . . . and other than co-assembly of McDonnell Douglas passenger aircraft . . . China's capability for producing transport aircraft is limited to short-range and medium-range turboprops. Chinese helicopters in production are all based on European models.

The same study noted that “China has an impressive [space] launcher capability *for a developing country*” (emphasis added), but that “China’s satellite capabilities are less impressive than its launch capabilities” (Cliff, 2001, pp. 27–28).

China’s military modernization drive since the late 1990s, however, has resulted in important structural reforms and increased resources for its aerospace industries, and China’s aviation sector has become increasingly involved in supplying civilian aircraft components to major foreign manufacturers.¹ Progress has been rapid. China is now able to produce modern military aircraft, highly reliable space launch vehicles, a wide range of military and civilian satellites, and an increasingly wide and sophisticated range of components for Western airframe and engine manufactures such as Boeing, Airbus, Eurocopter, Pratt & Whitney, GE, and Rolls-Royce.

Nonetheless, important capability gaps remain. Many of the subsystems on Chinese-built military and civilian aircraft, particularly turbofan and turboprop engines, must still be imported. Despite ambitions since the late 1990s to develop a domestically designed regional or large airliner, China does not have such an aircraft in operation. And while a regional jet, the ARJ21, is now in testing, it uses foreign engines and avionics, the wing was designed with Russian help, and only a small fraction of the aircraft was constructed from composite materials; thus, even before it reaches production, whether it can compete with existing Embraer or Bombardier regional jets is questionable. Similarly, while China has initiated efforts to develop a large commercial aircraft, the C919, actual production is still years away. And even then, all of the major subsystems, such as the engines and avionics, are likely to be foreign-designed. China has not demonstrated the ability to independently design and produce innovative and commercially competitive aerospace systems.

Relatively few studies of China’s aerospace industry as a whole have been published in the past decade, but the rate of progress noted above has generally been consistent with past assessments. The 2001

¹ For the definitive account of the changes in China’s defense industries during this period, see Cheung (2009), especially pp. 101–234. See also Mulvenon and Tyroler-Cooper, 2009.

RAND study stated that “China can expect to make significant technological progress in coming years but cannot possibly catch up to, much less ‘leapfrog,’ the United States or Japan [in commercial technology] in the foreseeable future” (Cliff, 2001, p. 58). Similarly, a 2005 RAND study that examined only China’s military aviation capabilities (Medeiros et al., 2005, p. 201) noted that

Progress in China’s military-aviation industry is mixed and limitations persist. There remain important gaps in China’s military-aviation R&D and production capabilities that will not soon be filled. . . . Any programs under way to fill these gaps are only in their very formative stages.

The study concluded (p. 203) that

The technological gap between China’s military-aviation industry and that of the most advanced countries will likely continue to close in coming years, [but] China will certainly continue to lag behind these countries.

Thus, China’s aerospace manufacturing capabilities in 2011 appear to be largely consistent with what would be expected based on the 2001 and 2005 RAND assessments.

Future Developments

It seems likely that over the coming decade China will begin producing both a regional jet and a jetliner (the former being more certain than the latter). Whether these aircraft will be competitive outside of China, however, is less clear. Less of the ARJ21 will be made of composite materials than current Bombardier and Embraer aircraft, meaning that it will be heavier. In a market in which fuel efficiency is a key characteristic, it is not clear why airlines would choose to forgo brands with proven safety and reliability records to purchase an unproven and less-efficient aircraft. Nonetheless, it appears that China’s domestic airlines, encouraged by high tariffs for foreign-designed regional jets

and possibly more direct pressure from the Chinese government, will purchase a certain number of ARJ21s, and some state-owned carriers in Third World countries may also purchase the ARJ21 in return for diplomatic or other considerations. Thus, COMAC may wind up selling enough ARJ21s to, if not actually turn a profit, at least justify the investment in a learning process that will enable its *next* generation of regional jets to be commercially competitive outside of China. Within China, however, given the tariffs on foreign-designed regional jets and the relatively small size of the Chinese regional jet market, the ARJ21 is likely to dominate.

The story for the C919 is similar. The precise design of the aircraft has not yet been finalized, so how advanced it will be is unclear. However, its announced weight relative to its length and capacity suggests a design no more advanced than that of the 1980s-era A320. Moreover, initial deliveries are not expected before 2016, and Boeing and Airbus could easily develop and bring to market a more advanced narrow-body jetliner by then if the C919 appeared to threaten their market shares. Bombardier and Embraer are eyeing the narrow-body market as well, as are Russian and Japanese aviation manufacturers, so the narrow-body jetliner market in the coming decade is likely to be extremely competitive. Thus, the commercial success of the C919 is far from assured, even though China undoubtedly has the capability to manufacture an aircraft in this class. As with the ARJ21, China's domestic airlines will purchase a certain number of airframes but, unlike the case of the ARJ21, the majority of narrow-body jetliners sold in China could well be foreign-made, even after the C919 comes to market. And until China develops a wide-body jetliner, all such jetliners sold in China will be foreign-made. Again, as with the ARJ21, however, the C919 program may ultimately be valued not for the profits it produces but for the learning experience it provides, enabling China to acquire the skills needed to develop a commercially competitive aircraft in the future.

The helicopters China produces under license from or has co-developed with Eurocopter are unlikely to generate significant export sales, as each type also has production lines in France. However, the existence of domestic production capabilities for a growing range of

helicopters may mean diminished sales in China for non-Chinese helicopter manufacturers. The huge potential demand for helicopters in the country, moreover, may mean that additional types will be developed over the coming decade, possibly purely domestic designs.

China's fixed-wing general aviation manufacturing capabilities seem unlikely to develop rapidly in the near future. Current production capabilities are extremely limited, and the lack of a significant domestic market for fixed-wing general aviation has resulted in little immediate incentive to expand these capabilities. As of 2006, Dassault Falcon Jet Corporation expected China to acquire 300 new business jets by 2015 (Sun, 2006), but China does not currently produce any business jets, and none are under development.

If the development of the CZ-5 series of launch vehicles is successful, China's space launch capabilities will improve significantly in the future. The CZ-5 series will roughly triple China's lift capacity to both LEO and GEO. Also, a new generation of lighter launch vehicles, the CZ-6 and CZ-7 series, is under development and should increase the efficiency and cost-effectiveness of China's space launch capabilities (Perrett, 2010d, pp. 22–23). The reliability problems that plagued China's space launch vehicles in the 1990s seem to have been resolved, so the primary limitation on China's competitiveness in the commercial space launch market today is U.S. export restrictions. The effect of these restrictions is likely to erode in coming years, however, as non-U.S. satellite companies develop an increasing range of satellites without U.S. technology content.

Near-term prospects for China's satellite capabilities are less promising, given the problems that have plagued the DFH-4 platform. However, there is no reason to believe that these problems will not be resolved in the next few years, providing China with the basis for an improved military satellite-communications capability, as well as increasingly competitive commercial communications satellites. China's surveillance- and reconnaissance-satellite capabilities can probably already satisfy the majority of military requirements and will undoubtedly improve further over the next decade, with greater resolution and the possible deployment of an X-band ocean-surveillance radar satellite. As these capabilities improve, China may acquire the option to

enter the commercial satellite imagery market without compromising its military imagery satellite capabilities. China's Compass PNT satellite system seems to be on schedule and, if so, will provide worldwide coverage by 2020. This will provide China with an alternative to relying on the U.S. GPS and Russian Glonass system for military purposes. Whether there will be a revenue-generating commercial market for the Compass system, given the availability of the free public GPS system, however, is questionable. Finally, China will continue to develop and deploy improved weather satellites in future years. Thus, by 2020, China will likely have a fully deployed PNT system, high-capacity civil and military communications satellites, high-resolution surveillance and reconnaissance satellites, and highly capable weather satellites.

Potential to Contribute to China's Military Capabilities

Military and civilian aerospace technologies do not overlap in all areas. Many military-specific aerospace technologies, such as low-observable technology, low-bypass afterburning turbofan engines, electronic countermeasures, and signals-intelligence satellites, do not have civilian counterparts. Similarly, many civilian aerospace technologies do not have military applications. Nonetheless, there are areas of overlap, including computer-aided design and computer-aided manufacturing technologies, precision machining, composite materials, high-bypass turbofan engines, flight-control systems, space launch vehicles, communications satellites, and imagery satellites. Thus, foreign involvement in China's civil aerospace sector unquestionably has the potential to contribute to the development of China's military capabilities.

Even the manufacturing of components for Western aircraft and engines probably provides some contribution to the development of China's military capabilities, to the extent to which Chinese enterprises also involved in military aviation production do so, even if no direct technology transfers are involved. The mere act of machining parts to the specifications of Western aerospace manufacturers provides training that is potentially applicable to the machining of parts for military

aircraft, especially if representatives of those Western manufacturers are present onsite to provide training and guidance in quality control. And the revenues generated can be used to upgrade the facilities and machine tools of both civilian and military production lines.

Joint ventures can enable the direct transfer of manufacturing technology into China, as can the transfer of production licenses (depending on the amount of technical assistance provided with the transfer). Some platforms and technologies are inherently dual-use. The Eurocopter AS365N is a medium utility helicopter with numerous civilian applications. The license-produced Chinese version (Z-9), however, is used primarily by the Chinese military.

When foreign companies cooperate with Chinese enterprises in the development of new systems, the potential to contribute to the development of China's military capabilities is even greater. As noted in Chapter Four, in 1997, Eurocopter received a contract to assist China in developing a new 6-ton transport helicopter. No new transport helicopter was developed as a result of that project, and it appears that China instead applied the technology acquired to the Z-10 attack helicopter, which is in the same weight class. Similarly, the knowledge Chinese companies acquire through foreign assistance in the development of the ARJ21 and C919 could in the future be applied to the development of military airframes. Indeed, aside from acting as troop transports or military cargo aircraft, the ARJ21 and C919 airframes themselves have the potential to form the basis for a variety of special-mission aircraft. Airborne early-warning aircraft have been built on the Embraer ERJ-145 airframe; the U.S. Air Force Airborne Warning and Control System (AWACS) aircraft and Joint Surveillance Target Attack Radar System (J-STARS) are built on the Boeing 707 airframe; and the U.S. Navy's new P-8 maritime patrol aircraft is built on the Boeing 737 airframe.

Similar arguments apply in the space sector. The German company Daimler-Benz was reportedly involved in the development of the DFH-3 communications satellite platform (Cliff, 2001, p. 28), which is the platform used by China's two military communications satellites. Similarly, collaboration with Brazil in the development of the

CBERS satellites undoubtedly aided the development of China's military reconnaissance satellites.

Implications for U.S. Security Interests

As noted earlier, there is no question that China's growing civilian aerospace capabilities are contributing to the development of its military aerospace capabilities. Many aerospace systems are inherently dual-use—for example, commercial airliners can be used as military transports and as the basis for special-mission aircraft. High-bypass turbofan engines used on airliners share components of low-bypass turbofan engines used on high-performance aircraft (the General Electric F101, originally developed for the B-1B supersonic bomber, became the basis both for the F110 fighter engine used on the F-16 and for the CFM56, the best-selling airliner engine of all time (“General Electric F101,” 2010). Autonomous flight-control systems can improve the safety and performance of passenger aircraft but can also be used on military unmanned aerial vehicles. Space launch vehicles can be used for either military or commercial launches, and many satellite types, including communications, PNT, and weather satellites, have both military and commercial applications.

Many of the skills and technologies required to produce commercial or dual-use aerospace products are also applicable to purely military systems. These include computer-aided design and computer-aided manufacturing, precision machining, and composite-material manufacturing.

There is also no question that China's growing aerospace capabilities have implications for U.S. security interests. Beijing claims that the autonomous island of Taiwan is part of its territory and reserves the right to use force to bring about unification, but the United States has declared that any threat to Taiwan's independence would be a threat to its own interests. Similarly, a Chinese attempt to assert control over territory it claims in the East China Sea and South China Sea would affect U.S. interests in the freedom of navigation and in the security of U.S. allies who also claim some or all of those territories. Thus, China's

growing aerospace capabilities increase its ability and possibly its propensity to use force in ways that negatively affect U.S. interests and would increase the costs—human and material—of resisting attempts to use such force.

However, it is difficult to quantify the extent to which improvements in China's civilian aerospace capabilities in general, and international cooperation in the civilian aerospace sector in particular, are driving improvements in China's military aerospace capabilities. China's defense spending has quintupled in real terms since 1995, a greater than 12 percent annual growth rate. This means that vastly more resources are now available for the development of aerospace and other defense capabilities than were available just 15 years ago. Moreover, China's military aerospace industry has benefited from direct technical assistance from Russian, Israeli, and other foreign firms and technical experts. With China being one of the world's largest trading nations, China's military aerospace industry can purchase state-of-the-art parts and technologies from throughout the world. The industry also has the ability to tap into expertise in firms outside of the aerospace sector and in Chinese universities, which themselves are increasingly integrated into the world scientific and engineering community. Finally, China is engaged in large-scale espionage efforts to acquire key aerospace and other military technologies.

The technologies being transferred to Chinese firms are in most instances not cutting-edge. Leading aerospace firms are generally reluctant to share their best technologies, because those technologies are the source of their competitive advantage. As an example, Rolls-Royce is unwilling to share its technology for forging unitary turbine rings (known as bladed-rings, or "blings") with its own wholly owned subsidiary in Indianapolis, preferring instead to keep this "crown-jewel" technology at its facility in the United Kingdom.² Out-of-date Western technologies, however, can still be new technologies to China, which, for example, has yet to master the technology for turbofan engines, which first entered production 50 years ago in the West (Younossi et al., 2002, pp. 9–24). But the nature of the aerospace

² Interview with Rolls-Royce representative, 2003.

technologies being transferred to China and the range of alternative technology sources available make the U.S. security policy implications opaque. Since it is difficult to quantify the degree to which international cooperation in civil aerospace is assisting the development of military aerospace capabilities in China, whether even a complete cutoff of such cooperation would substantially slow that development is equally unclear. A complete cutoff, moreover, would be impractical. Russia in particular is unlikely to go along with a U.S.-organized ban on cooperation in civil aerospace with China, and whether European and other Asian countries would do so is also questionable. A U.S.-only ban would likely slow the development of China's military aerospace capability by only a small amount while handing business opportunities to European and Asian companies and aggravating relations with Beijing. At a minimum, a smart U.S. policy would limit restrictions to cooperation in technology areas that are not available from other countries or in which other countries that also possess those technologies are willing to coordinate with the United States in imposing restrictions.

China's emergence as an aerospace power is perhaps inevitable but hardly an accomplished fact. It will be at least another decade before China has reached today's state of the art, and by then, the state of the art will have moved further ahead in ways that are, by the nature of technological discovery, fundamentally unknowable in advance. U.S. and other Western companies are deeply involved in China's aerospace development, and although this is unquestionably contributing to the development of China's military aerospace capabilities—capabilities that one day might be used against the United States—those companies are reaping profits for their American shareholders and keeping Americans employed, even as they transfer lower-value-added production to China. They are also helping raise the standards of living of some of the one-fifth of the world's population that lives in China, increasing their ability to buy American-made products. And war with China may never come. The policy choices here are far from black-and-white, and it is unclear whether the United States could significantly improve its security through alterations of its policy toward civil aerospace cooperation with China without having a significant negative effect on U.S. economic interests.

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